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FOREIGN TECHNOLOGY DIVISION

AEROSPACE ACTIVITIES IN MODERN CHINA

(Chapters 1-3, Part 4)

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AEROSPACE ACTIVITIES IN MODERN CHINA

PART FOUR [text pages 360-437]

Aerospace launch sites, ground surface tracking and control networks, along with associated equipment, are important components in the aerospace engineering system; these components provide necessary and vital requisites for sending off carrier rockets and spacecraft. China's construction of aerospace launch sites and ground surface tracking and control networks has proceeded simultaneously with its construction of rocket and satellite research and development bases. In these construction projects, the engineering construction of aerospace launch sites and certain parts of stationary facilities are responsible for the experimental bases of the National Defense Science and Engineering Commission. Ground surface facilities are responsible, under the Ministry of Aerospace Industry and other units, for research, development, and complete-set manufacturing. With expanding development of China's aerospace technology and aerospace activities, several stages of engineering construction have been successively completed at launch sites as well as tracking and control networks. There are different models and technical status for ground surface facilities, thus forming relatively complete-set systems, in satisfying China's demands for launching various types of carrier rockets and artificial satellites.

Materials, technology and various experimental facilities are the technical foundation of aerospace engineering. The technical advancement and overall characteristics of aerospace engineering impose very strict requirements on materials, technology, and experimental techniques. To furnish raw materials, supplies, components, and experimental equipment required in aerospace engineering, large volumes of research, experiments, and trial manufacture were conducted by China's various industrial departments and scientific research units, thus greatly enhancing the technical level of the fundamental industries.

In this part, the book mainly presents the following: construction process and major technical facilities of China's aerospace launch sites and ground surface tracking and control networks, special materials and processes developed for aerospace engineering, as well as the major large ground experimental facilities and equipment.

CHAPTER ONE: AEROSPACE LAUNCH SITES AND GROUND FACILITIES

Section 1: Functions of Launch Sites

A launch vehicle can place artificial satellites in a space orbit; launching is inseparable from the perfectly functioning facilities of the launch site, and the outstanding characteristics of ground support equipment.

The launch site is the last mooring-point on the ground before the rocket enters the vast universe. The site is composed of various types of fixed, semifixed, and mobile ground support equipment and engineering facilities. In China's early-stage relatively simple launch sites there were only the underground control rooms, a paved cement apron, and few units of equipment. With development of China's carrier rockets as well as the enlargement of external rocket dimensions and lift-off capacities, the scale of launch sites and the capacity of ground facilities have changed significantly. Many ground facilities have become fixed installations on the launch site. Thus, the launch site and the ground facilities are more and more closely interconnected.

Ground facilities: this is a general term for the special equipment and installations required during the preparatory stage and launch process when a rocket or satellite is to be launched. Smoothly performing ground facilities are used to tame this large

mighty rocket, so that it can be subjected to man's will. Otherwise, the rocket may self-destruct along with launch

Fig. 97. Large rocket on launch pad

Fig. 98. Large rocket on a transporter on highway

personnel if something goes wrong. Although a rocket can generate hundreds of tons of thrust, however, its casing is quite delicate--a dent can be inflicted even with a small stone. From high-altitude area to low-altitude zone, accidents may occur that involve the collapse of the fuel tank due to differences in atmospheric pressure. Various kinds of propellants--some are toxic, some are highly corrosive or very volatile, or easily combustible or explodable. These factors impose severe and strict requirements on various items of equipment used in propellant storing, transporting, and filling. To send off a large launch vehicle, hundreds of tons of propellant are required. These propellants should be reliably and precisely loaded into the rocket fuel tank; the filling should be just right, not too much or too little, else serious consequences may result. So during the filling process the propellants are not

allowed to leak, otherwise the process will cause damage. From the general rocket assembly plant to rocket transporting and erection on the launch platform, there are many steps of transshipment and status conversion; the quality of hoisting and installation equipment is closely related to whether or not the above-mentioned tasks can be smoothly accomplished.

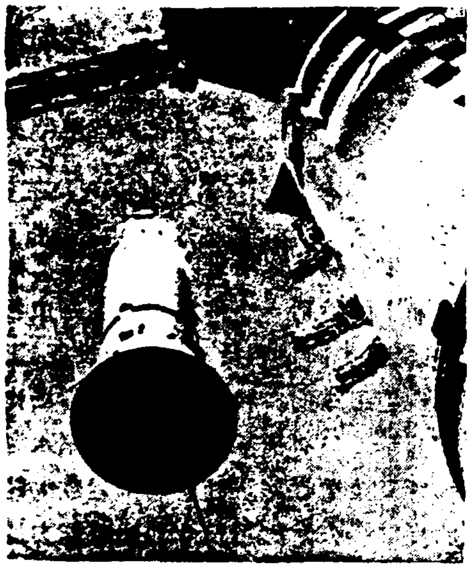

Fig. 99. Hoisting and stage connection of rocket

Rocket launch sites and ground facilities in China serve multiple purposes, either to conduct weapon tests of guided missiles or to use these facilities in sending up carrier rockets. In the past three decades, hundreds of items of ground facilities were developed for launch sites. These developments of complete sets of this equipment are scattered over more than 60 factories and research institutes (located in more than 30 cities) under the ministries of machine-building, railways, ordnance industry, chemical industry, public security, and

aerospace industry, as well as the Chinese Academy of Sciences. As for the secondary accessories, raw materials and supplies, and other components, these are made or coordinated in an even larger number of departments. In the spirit of vigorous coordination, these units are technically coordinated in pace and quality, thus meeting the test and launch requirements for rockets and satellites in making contributions to progress in China's aerospace activities.

Section 2. Launch site construction

Generally, there are three stages in aerospace launch site construction in China. At the beginning, China's first rocket launch site was built in the Jiuquan area in order to master rocket launch techniques, to train rank-and-file personnel and to acquire experience. China's first short-range rocket was sent off from the Number Three Launch Site Zone of this launch site in 1960. Subsequently, the Number Two Launch Site Zone was built as an achievement of Chinese design, thus satisfying the requirements for launching multistage rockets and various types of satellites. China's first artificial earth satellite in 1970 and long-range rockets fired over the Pacific Ocean in 1980 were sent off from this Number Two Launch Site Zone. According to the requirements of China's aerospace development and in order to make a complete line of China's launch facilities for launch satellites and satellites, the Southwest Aerospace Launch Site began to be built in 1978. China's first experimental communication satellite in 1984 was sent off in this southwest site.

1. Number Three Launch Site Zone

After exploration and investigation, early in 1958 it was decided to build China's first rocket launch site in the Gobi Desert, north of Jiuquan. Here, the site is distant from large

cities--"flat expanses of sand extending tens of thousands of li, very sparsely populated." In the vast Gobi Desert, without any end in sight, there are very few plants except brushes of brown camelthorn. Only yellow goats and wild deer can be seen here or there. In ancient times, this area was the necessary passage from the Mongolian Plateau to the Hexi corridor. During the Han Dynasty, county administration was set up there along with border guard plantations and a section of the Great Wall to defend against the Huns invading to the south. A Tang Dynasty poet, Wang Wei, wrote the following poem: "Hunting for swans outside of the capital Juyan city/Wildfire of whitish glass to the end of the horizon/Driving horses under a dusty cloud toward the featureless sand/Autumn days in the flat land provides good eagle shooting occasions." This poem shows that there is not only an important border for the defense of the motherland, but also grazing land of Mongolian herdsmen.

The first main construction in the first launch construction location of the Number Three Launch Site Zone is a cement-covered flat a little higher than the surrounding Gobi Desert; the cement flat is generally elliptical in shape, capable of parking more than ten large vehicles. There is a square foundation for the launch pad in the center. In the basement of the square foundation, a set of lever-type platform scales was installed to weigh rockets before and after propellant filling. There were several cement emplacements at the margins for parking launch control vehicles, power supply vehicles, and firefighting vehicles, composed of a rudimentary warehouse and a lot of cement flat, a transshipment depot is hundreds of meters from the flat inlet direction.

To speed up construction of the launch site, a special engineering command post was established, which had a basic assembly, construction, and test base in the headquarters of the 20th Corps of the Chinese People's Liberation Army. Some of the

corps' commanders and combat personnel, along with a unit of engineering troops came here to build the related engineering and living facilities of the launch site. At that time, all construction equipment and living necessities had to be transported from the inland provinces. In the initial stage, even water for living had to be brought in by truck from far-off locations; such difficult conditions can be imagined. The engineering corps commanding general, Chen Shiju, and the 20th Corp commanding general, Sun Jixian, commanded this unit; they attained an outstanding achievement in overcoming difficulties in building China's first launch site in this barren border area.

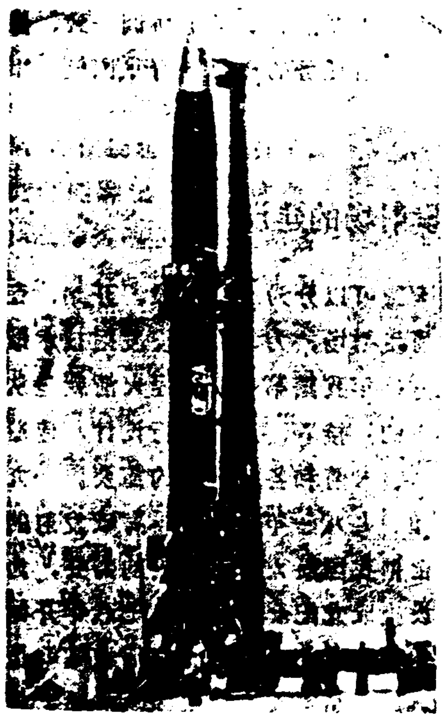

Fig. 100. Erection of rocket at the Number Three Launch Site Zone

Together with the successive arrival of technical cadres, this unit of troops encamped on this age-old Gobi Desert to struggle in building the launch site with tough struggles in well drilling, tree planting, filling up artificial lakes, and building of railroads. Eventually, the age-old sleeping land was

awakened with diligent labor to bring forth new vigor and vitality to the Gobi Desert of bustling horses and soldiers. Lane after lane of cement-covered highways penetrate into the desert with rows of two-story buildings and along with willows and white poplar to form groves. Set after set of heavy equipment were also installed in this barren desert. The first rocket-testing base appeared miraculously in this yellow-sand tract devoid of greenery, as the ancients called it.

In November 1960, the first rocket copied by China was launched in this launch site zone. After several days of measurement and testing at a test factory building, this rocket was loaded onto a transporter; after passing a section of cement-paved highway more than 30 km long, the transporter entered a transshipment depot of the Number Three Launch Site Zone. Stationed there, a tall lifting crane hoisted the rocket onto an erector crawler, which moved at a walking pace loaded with the rocket to slowly enter the launch pad. The hydraulic equipment on the erector erected the horizontally positioned rocket to a vertical position, to be placed on the launch pad. Successively, the operators climbed up the three stories of the working platform, in beginning to conduct vertical measurements and tests of the rocket, loading propellants, installing batteries and combustibles.

Party and state leaders paid close attention to this launch. The State Council vice premier, Nie Rongzhen, and the Liberation Army chief of staff, Zhang Aiping, arrived at the site to command. They imposed very strict requirements on the operation. Every operational post should have two guards stationed there, shared by the test base and the development unit. In addition, various precautionary measures were prescribed. These double-guard post system and precautionary measures provided precedents for later tests, fulfilling valuable functions in preventing accidents during operations and the launch process.

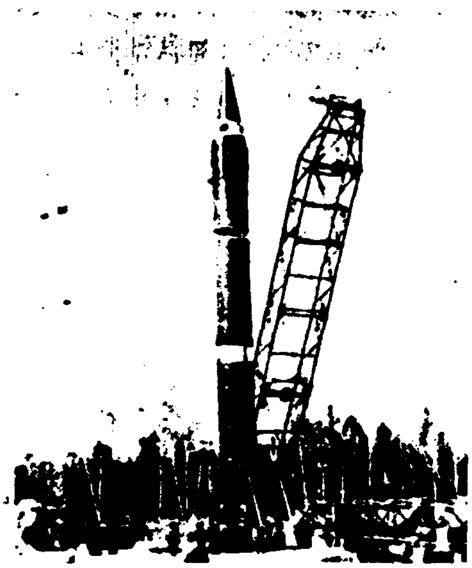

Fig. 101. Erection of a long-range
and placement on the launch pad

Compared with launch sites built successively, this launch site zone appeared simple and crude. However, over the span of more than two decades, tens of launch tests of guided missiles and rockets were held there to train rank-and-file personnel and to gain experience in developing China's technology in guided missiles and rockets.

2. Number Two Launch Site Zone

Beginning in 1965 and according to China's development planning of space technology, the Number Two Launch Site Zone with two construction sites was built at the Jiuquan launch site, capable of launching multistage carrier rockets and artificial earth satellites.

The construction of this launch site zone was divided into two stages.

In the first stage of engineering construction, the "5020" operational site was begun in 1965 and completed in early 1967.

The most majestic facility of this launch construction site is the 55-m tall Number One Gantry Tower, with a total weight of 1400 tons (including a 400-ton weight for enhancing stability). This gantry tower can be moved slowly on a heavy-duty steel rail track connecting these two construction sites. There is hoisting equipment at the top of the tower for hoisting and installing, stage by stage, the multistage rocket and satellite, for stage connection at the launch pad. There is a multistory working platform inside the gantry tower, which is then spread apart to enclose a rocket at its center to facilitate carrying out various measurements, tests, adjustments, and installations for rocket and satellites. An electric elevator is installed in the gantry tower for operational personnel and equipment. This set of facilities was designed according to the specifications provided by the Launch Vehicle Research Academy, designed by the National Defense Engineering Design Institute in 1965, and manufactured by the Taiyuan Heavy-Duty Machinery Plant.

At this launch construction site, there is a 37-m high fixation tower, which is used to install and fix various kinds of gas and liquid pipelines, as well as cables. Through these pipes and cables, measurements, tests, power supply, gas supply, and propellant loading are conducted for a rocket, in addition to firefighting tests, if necessary. Since many cables and pipelines connected to the rocket before launching, this fixation tower is also called an umbilical tower.

During the launch of a long-range launch vehicle, the flame temperature at the engine exhaust is more than 1000°C, capable of

igniting and destroying nearby objects. The flow rate of exhaust gases leaving the exhaust nozzle is nearly 3 km/s, eight to nine times the speed of sound. These exhaust gases have not only a tremendous reaction force, but also disturb nearby air to cause objects not firmly attached or even iron blocks on the ground to be set in motion, thus causing havoc. The flame deflector trough serves to guide the exhaust gases generated after rocket ignition, to avoid damage to launch site facilities and the launch vehicle itself. Although the launch pad bestriding the flame deflector can be moved, the launch pad is much higher than the launch pad in the Number Three Launch Pad Zone. Generally, the launch pad is parked for a long time on the launch operating site, becoming a semi-fixed item of equipment.

During launch preparations, there are many different sizes of pipelines and cables connected to the rocket; most of these pipelines and cables will be detached from the rocket at the instant just before ignition. There is a rotary installation on the tower to rapidly swing all the plugs detaching from the rocket to the side in order to prevent collision with the rocket hull.

Among the fixed facilities of the "5020" operational site, there is an underground control room, two propellant storage rooms, storage room for high-pressure gases, a targeting room, and a photography room, among others; these facilities have certain protective capabilities. In addition, there is a water supply system, sewage treatment system, and an alarm system, among others.

The control room is a hemispherical reinforced-concrete structure, buried more than 10 m underground. This type of domed structure has high capability of withstanding external pressures, even if some accidents occur before or after rocket flight, the personnel and equipment inside the control room can be safe and

secure. There are various machines and consoles in the control room, in addition to instruments, meters, and communication facilities. In order to facilitate the observation of the erected rocket on the launch pad, there are an industrial television and two periscopes. The main basis for the command task includes various signal and digital displays.

After completion of this operational site, launch tests of intermediate and long-range rockets were conducted. In April 1970, Changzheng (Long March) Number One launch vehicle lifted off China's artificial earth satellite; in March 1970, a scientific experimental satellite was also launched here.

The "138" operational site was built at the second stage of engineering construction. The site is located 400 m northeast of the "5020" operational site; this is a launch operational site for heavy satellites. In 1967, when the operational site began to be designed and built, this was during the Great Cultural Revolution; there was confusion all around. Many factories under contract to manufacture equipment, such as, the Shenyang Heavy Machinery Plant, overcame various difficulties during these occasions of very abnormal production conditions to accomplish their production missions on schedule with quality and quantity as specified, thus ensuring the construction pace. This operational site was completed in 1970, becoming China's foremost launch operational site for rockets. Most rockets carrying satellites were launched here.

In this operational site, the umbilical tower is 11 stories tall, totalling more than 40 m in height. Five of the stories were installed with mobile work platforms, capable of approaching the rocket. The exhaust gas flame deflector trough is approximately 19 m deep from the ground surface; the trough was built with reinforced concrete; on some sections of the trough, high-strength and high-temperature-resistant cement served in

paving the surface. Thus, the trough will not crack or be stripped after multiple uses after being impacted with high-temperature and high-speed exhaust gas flows.

The launch pad on the "138" operational site is a force-bearing installation capable of being rotated. On this "rotary chair," a launch vehicle of about 200 tons weight can be rotated along the direction displayed by the targeting instrument through the electrical, gas, and hydraulic systems. Four branch arms supporting the rocket should be flung off the instant of ignition to ensure smooth rocket takeoff.

The "138" is a multipurpose launch operational site, not only for launching multistage carrier rockets with high thrust, but also to secure rockets at this operational site for hot test runs (otherwise known as tethered ignition) for all rocket systems. After completion of this operational site, all systems hot runnings in a large Fengbao No. 1 launch vehicle were tested in March and April 1971. Successively, in September 1971, launch tests of China's intercontinental rocket were conducted here. In July 1975, the Fengbao No. 1 launch vehicle was used to launch a heavy satellite; following closely behind, a Changzheng No. 2 launch vehicle was used to launch a reentry type satellite. In May 1980, long-range carrier rockets were launched here toward the Pacific Ocean. In 1981, a rocket was launched here for a set of three space reconnaissance satellites.

3. Southwest Aerospace Launch Site

The Jiuquan Launch Site in Northwest China has its geographic site north of 40^{o} N. Lat.; the launch site is very disadvantageous to launching communication satellites with the requirement that the orbital plane be coincident with the equatorial plane. In order to send the communication satellite into a geostationary orbit 36,000 km high, the satellite weight

when entering orbit will be much smaller if the same thrust launch vehicle is used to launch at the Northwest Launch Site located at more than 40° N. Lat, compared with a launch near the equator. By utilizing all advantages of the vast motherland, the state decided to build a new aerospace launch site in the southwest. The natural environment in southwest China is much different from that of the Northwest Launch Site. Here the terrain is hilly, with scabland, and the climate is humid and foggy. In May and June each year, after entering the rainy season, there are very few days of completely sunny. The following problems exist in building launch sites here: concrete solutions should be here for lightning arresters, moisture-proof and earthquake-proof.

Prospecting, exploration, site determination and other preparations for this construction project began as early as 1970. However, engineering progress was very slow, due to disturbances during the ten years of the Cultural Revolution. After the Gang of Four was smashed and especially after the Third Session of the Eleventh Party Congress, the project had a new start, with a gradually speed-up in pace. In 1982, the first stage of engineering construction was completed, mainly the launch operation sites and corresponding facilities for the geostationary synchronous satellite.

An operational tower loomed high at the launch site; this tower is higher, by 22 m, than the number one gantry tower in the Northwest Launch Site. There is only one operational site here, therefore no mobile mechanism is necessary. With an overall weight of more than 900 tons, the operational tower is fixed on its foundation; the tower will do the work normally done by two facility items in the Northwest Launch Site: the number one gantry tower and the umbilical tower. Structures of facilities such as launch pad and exhaust gas flame deflector trough are basically similar to those in the Northwest Launch Site.

The 77-m tall operational tower is not the tallest structure here. Delta-shaped in layout, three lightning arrester towers were erected on the launch site, each more than 100 m in height. Like three protective gods, these towers protect this launch site.

In an underground tunnel several kilometers from the launch site, there is a command and control hall. Here there was installed a general command platform developed by the Shanghai Scientific Instrument Plant and a large composite-type display screen, 18 m wide and 6 m high; there is a color television screen in the center of the display screen; the television screen is 5 m wide and 3.75 m high. Before launch, the screen shows the television picture of the launch complex. After the launch vehicle takes off, the television screen shows the real-time trajectory curves and the characteristic point parameters during the launch vehicle flight. On this large screen, there are also a display panel for dispatch word of command, a display panel of the impending launch status of the complex, two projection television screen, a display panel of the subsystem status of the complex, a display panel showing the operation of ground support equipment, a display panel showing the flow chart, a display panel showing the parameters of flight operation status, a time display panel, and a mission status panel. By using this modernized launch command equipment in the launch site, at a single glance the commander can grasp the complete process before and after the launch.

In early 1983, the entire system (launch site, rocket, satellite, and ground facilities) joint maneuver was conducted in order to inspect coordination and suitability of all facilities, and ground support equipment, on the one hand, and the rocket and the satellite, on the other, in the launch site. During launching of conventional propellant rockets, the development and

testing department accumulated a wealth of experience; however, this was the first time for the launch of low-temperature liquid propellant rockets. As shown in the joint maneuver, most of the main problems emerging were related to low temperatures. Therefore, some suitability revisions were conducted on the launch facilities. To reduce the flow resistance of hydrogen in the ground discharge system, the discharge pipeline was subjected to relatively major improvements. In the ground gas supply system, a set of hydrogen heating systems and installations was added to provide warmth in the rocket engine compartment, to ensure operational reliability of the attitude control engine inside the compartment.

Fig. 102. Command and control hall

In April 1984, the Changzheng No. 2 launch vehicle took off from here to successfully send an experimental communication satellite into a predetermined orbit.

Up to this time, China's aerospace launch sites have been located in high-latitude and low-latitude regions, to either launch the conventional-propellant rockets or to launch low-temperature, high-energy propellant rockets, and to either test

single-stage intermediate short-range and intermediate-range rockets, on the one hand, and also to test multistage intermediate long-range and long-range rockets. Thus, China has a complete test and launch base to send off carrier rockets and satellites, thereby establishing a solid material foundation for further development of aerospace activities.

In order to launch rockets into space and send satellites into orbit, it is insufficient if there is only the correct design schemes for rockets and satellites and highly specialized manufacturing technology. Similarly, launch tests require capable commanders and large numbers of highly technical operational personnel. Over the past three decades, the commanders, combat personnel, and engineering technicians in China's launch site zones and stations learned a set of strategies in overcoming difficulties. Whether in launching, tracking, or control, and standard time, on the one hand, or in climate, data processing, or protective work, numbers of capable personnel have been trained. This is the fundamental guarantee for smooth progress in testing work.

Section 3. Ground Machines and Equipment

On a rocket launch site, ground support equipment serves in rocket launching with functions similar to ground logistic equipment in an airfield, but with more variety and greater complexity. Based on their functions, several subsystems can be divided: hoisting equipment for elevating, reloading, and stage connection and satellites, transportation equipment on highways, railways, and waterways for transshipping rockets and satellites, launch support equipment for perpendicularity and direction adjustment for rockets and their support, propellant top filling equipment for reloading and top filling, acceptable gas and gas supply equipment for rockets, satellites, and some ground facilities (such as top filling equipment and temperature control

equipment), power supply equipment for power supply and distribution, for rockets, satellites, and some ground facilities, ground targeting equipment for initial positioning and orientation of rockets, tracking, testing, and launch control equipment for horizontal and vertical tracking and testing of rockets, as well as the final ignition launch control, temperature adjustment equipment, as well as supplementary equipment and installations for maintenance, repair, and safe use of ground support equipment and facilities for rockets and satellites.

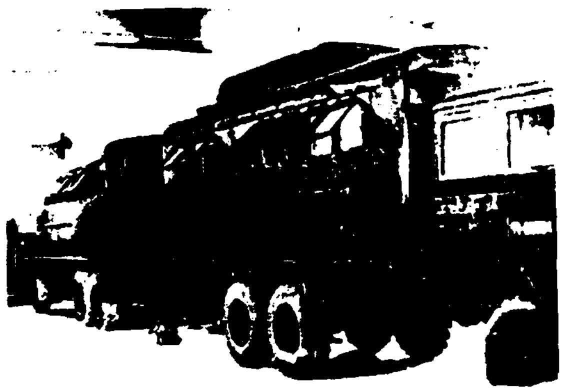

Fig. 103. Air compressor vehicle and mobile nitrogen preparation equipment

The development of ground support equipment in China went through the process from copying to the self-design and independent development.

The ground support equipment used for China's first rocket launch was imported from abroad with obsolete and backward technology. However, the importation serves the function of starting a learning curve for persons who had never before seen a modern rocket up till then. In 1958, design personnel went to factories to take part in copying and in handling of technical problems, thus having important functions in successful manufacture, on a provisional basis, and the training of rank-and-file personnel. During trial manufacturing of propellant top

filling equipment at a top filling equipment plant, there were two key components (eddy flow pump and a rotary flowmeter) that have never before been available in China and without any accompanying blueprints. In order to solve these key technical problems, Chinese scientific and technical personnel followed the spirit of self-reliance and by referring to sample measurements and drawings, eventually succeeded, through a trial-and-error process. A gantry crane manufactured on a provisional basis by a launch equipment plant was constructed of 27,925 individual parts of 2,275 kinds. Based on the types and specifications of the original drawings, fewer than one-half of the raw materials and supplies and finished parts could be purchased; as for the other half, there were no technical data available. Workers and staff of the launch equipment plant applied their spirit of unyielding practicality in overcoming difficulties upon difficulties, eventually succeeding in trial manufacture of this gantry crane to meet the preset requirements, thus participating in the hoisting and installation prior to the first launch of a made-in-China rocket.

Beginning in 1960 and based on copied equipment and by adopting the measures of improvements and enhancement, Chinese personnel designed a set of new ground support equipment with 38 types; 23 of these types were improved and designed from the original equipment or were of new Chinese design. For improving and enhancing the practicality of this set of equipment, ground support equipment development personnel exerted their maximum efforts in succeeding in design improvements, especially in multipurpose erecting support frames, liquid oxygen automatic top loading, railroad transportation vehicle, and peroxide warming and top loading vehicle, thus expressing the creativity of the Chinese people.

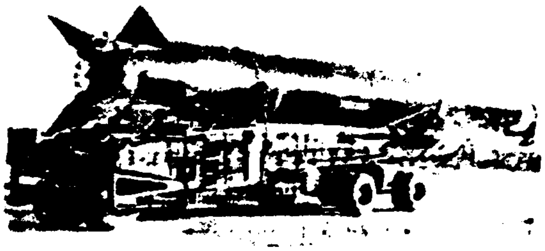

Fig. 104. Multipurpose erecting support frame

In the multipurpose erecting support frame, not only were adaptive modifications made to some of the original dimensions, of most importance was the addition of two layers of large-area operational decks on the erecting arm. During operation, more than one-half of the circumference of the rocket can be encompassed, thus providing convenience in measurements, testing, and installation for operational personnel. When the erecting support frame is not in use, the frame can be folded into a smaller irregular space without increasing the external dimensions of the support frame. The operational decks adopt the structure of a space truss, with lightweight materials, thus affording good rigidity and light weight. In addition, two kinds of functions of erecting the support frame and operational decks can be accomplished, thus achieving the purpose of reducing the number of equipment items and their costs.

From the original liquid oxygen top loading tanker, a set of automatic control devices was added to the liquid oxygen automatic top loading tanker; according to the high or low liquid level signals from the liquid level meters in the rocket liquid oxygen tank, opening or closing signals of high or low liquid

level are generated to operate the valves of a pressure vessel, thus achieving the functions of automatic top loading or load halting of liquid oxygen. When the rocket leaves the launch pad, the leakproof connector during loading is automatically detached. This is a vital measure in order to ensure that a rocket carries the proper amount of low-temperature propellant in its lift-off. Similarly to the foregoing, an automatic top loading device is also adopted in the third-stage top loading system of the Changzheng No. 3 carrier rocket; three minutes before the lift-off, the leakproof connector for top loading is detached.

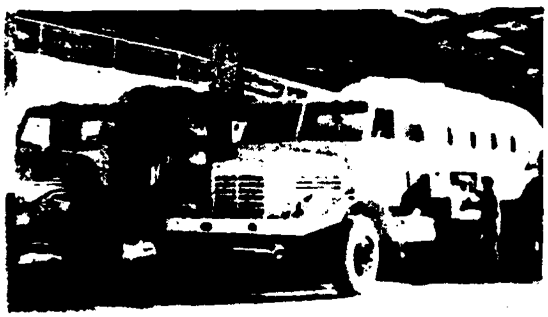

Fig. 105. Automatic liquid oxygen top loading vehicle

Previously, the imported composite type compartment structure was employed in the railroad transporter. Before and after loading the rocket, the compartment covers and the wall were disassembled and reassembled, piece by piece by using a crane; the process was complex and time-consuming. Supported by the Tangshan Locomotive and Rolling Stock Plant, the Ground Support Equipment Research Institute improved the design by adopting the design scheme in the shape of a passenger car to which a flatcar was attached. Thus, the rocket can enter or leave from the terminal door of the compartment; this greatly shortens the operating time. Other equipment can still be loaded onto the flatcar for transitional use.

Moreover, the peroxide warming and top loading equipment previously had been two items of equipment; these two items were combined into one item of equipment, the peroxide warming and top loading vehicle. The relatively heavy gantry crane with very complex operating procedures when converting transit status to operational status, was then modified into a saddle-type crane. Later on, a truck crane was modified further and used. These improvements and innovations were tested in practice, thus proving their good performance, convenient application with less workload and operating time.

When copying and self-designing were conducted, preliminary studies were carried out on some key technical items of ground support equipment. These studies laid a solid technical foundation for China's independent development of ground support equipment.

(1) To adapt to the development of heavy carrier rockets, a wheeled mechanism for 360-degree rotation was developed, thus enhancing the maneuverability and mobility during transportation. Beginning in early 1960, two different schemes of employing machine connecting rod mechanism and static hydraulic transmission mechanism were successively proposed and adopted to achieve synchronous turning of the front and rear wheel assemblies. Through repeated development tests and applications in ground transporter and erector equipment, satisfactory results were obtained. These two schemes were adopted in the mid and late sixties. The machine connecting rod layout is simple and convenient in use as well as low in cost. This achievement greatly enhances the mobility and maneuverability of various types of transporters.

The Changzheng No. 2, the Fengbao No. 1, and the Changzheng No. 3 are heavy rockets in China's family of rockets; all these three models are more than 3 m in diameter. The conventional,

standard compartments of rolling stocks on Chinese railways are incapable of accommodating them. Whether or not a type of special railcar capable of negotiating main tunnels in Chinese railways could be built was a key topic in rocket design schemes. With close cooperation between the Ground Support Equipment Research Institute and the Ministry of Railways, on the one hand, and its subordinate Tangshan Locomotive and Rolling Stock Plant, the scientists and technicians proposed a unique design layout. After nearly a year's simulated running tests on China's main rail lines, finally rocket diameters were decided on. Moreover, the unique scheme of high and low hook connection devices and low truck frame were adopted, thus solving this difficult problem.

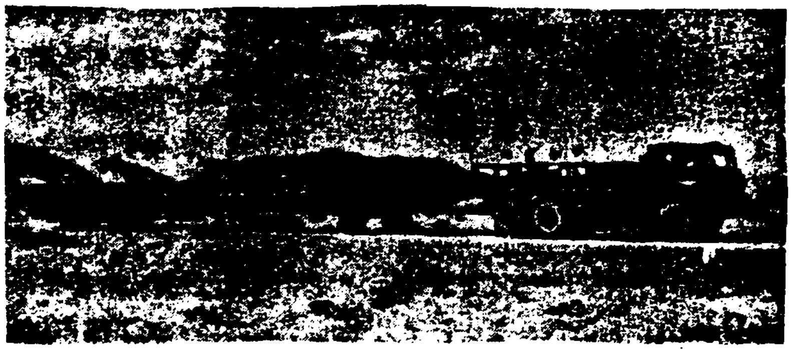

Fig. 106. Erecting truck and highway transporter employing a 360-degree and truss structure

(2) To solve the problem of heavy ground support equipment, truss structures and low alloy steel are used for erecting support frames and rocket highway transporter, thus reducing the weight and ensuring the requirements of strength and rigidity, as well as satisfactory technical properties. Previously, the I-beam shaped hanger assembly for rockets was composed of three large steel beams (one long and two short) and four hanger rods with a total weight of 350 kg. Later, with increasing rocket dimensions, the total weight of the hanger assembly approached 700 kg; this is not only heavy, but also complex in operation.

To adjust the position of the center of gravity and to ensure hoisting balance, it is required for the operator to climb over the back of the rocket to change the position of the plug-in pins. In the late sixties, a type of I-beam shaped hanger assembly was developed; these hanger assemblies can automatically adjust the position of the center of gravity, in addition to structural simplicity and convenient operation.

(3) For operational convenience and reliability, hydraulic, pneumatic, or electromotive operation is used to erect the support frame, launch pad, work platform, or hoisting machines, thus implementing operational mechanization and semiautomation. In 1977, four-way equalizing flow valves were developed to replace seven components in the previous system. Therefore, the elevating hydraulic pipeline system of four-support legs is greatly simplified.

Earlier, the gas supply connector of a single-stage rocket had been installed at the tail of the rocket; during launch, the connector is forced to detach. Multistage rockets do not employ this mode. In the late sixties, a new automatically separating connector was developed, thus solving the problem of automatic separation for the gas supply connector used with a multistage rocket.

(4) With the application and development of cryogenic technology, a series of requirements was imposed on the ground support equipment system.

Cryogenic hydrogen and cryogenic oxygen loading systems are composed of more than 50 items of equipment, including: cryogenic hydrogen railway transporter, cryogenic hydrogen highway loading vehicle, cryogenic oxygen transporter, hydrogen and oxygen pipelines, leakage control panel for filling, leak-proof gas distribution panel for filling, automatic monitoring and

recording system, as well as an exhaust gas discharge and processing system. This is cryogenic filling system of complex structure, highly advanced techniques, as well as high automation and reliability. The high-tech system is related to key techniques: vacuum insulation, cryogenic sealing, cryogenic inspection and measurement, two-phase flow, and noise immunity of electronic equipment. The system was developed by joint efforts of the Ground Support Equipment Research Institute and other related development units. After many years' effort by the Ground Support Equipment Research Institute and the Sanqiao Locomotive and Rolling Stock Plant, a cryogenic hydrogen railway transporter installed with a multilayer vacuum insulator was developed; there is only about 0.3% loss for a 24-hour period for this very highly volatile cryogenic liquid.

Fig. 107. Cryogenic hydrogen vehicle

Since the volatility is very high after the cryogenic propellant is filled into a storage tank of the rocket, before launch a never-ending refilling should be carried out through a refilling connector. Three minutes before the launch, this refilling connector can operate normally and reliably unattended; however, three minutes before the launch the connector can be reliably and automatically separated from the rocket. Design personnel at the Ground Support Equipment Research Institute

analyzed and studied various different structures, and automatically separating connectors; they proposed an automatically separating connector with a novel structure and reliable operation; these connectors are successfully used on Changzheng No. 3 launch vehicle.

Fired with cryogenic propellant, the rocket motor requires helium to supply additional pressure and start the turbopump, and control the pneumatic valves. At the launch site, the helium supply system consists of more than 30 items of equipment, including vehicles for helium bottles, diaphragm type compressors, spherical gas bottles, gas distribution panel, automatically separating connectors, in addition to pipelines, monitoring instruments, and helium warming equipment. The whole system consists of hundreds of meters of pipelines and thousands of meters of cable. The vacuum pumps and purifiers in the system ensure very high purity of the helium supplied to the rocket. Helium has a high infiltrability. Therefore, a series of leakage-proof measures are adopted in design. To solve the problem of operational difficulty and operational life of high-pressure valve components, new valves were developed, such as high-pressure equilibrium cutoff valves.

(5) To ensure aiming precision under poor weather conditions, such as gales or fog, in the early seventies laser tracking instruments were successively developed in joint efforts by the Ground Support Equipment Research Institute and the Shanghai College of Mechanical Engineering. The main features of this equipment are the adoption of laser long-range collimation, high aiming precision, high fog penetration capability, and effective distance over 100 meters. The orientation angle is shown on a digital display, in addition to transmission and printout. Moreover, there is a tracking attachment in the aiming instrument for swinging with the wind; during a gale with back-and-forth swinging of the rocket, targets can still be captured

and tracked. This is the first time in China for the application of laser technology in aiming equipment, thus filling a technical void in China. The technical performance of the laser aiming instrument is up to the level of similar products made abroad.

(6) To enhance mobility of ground support equipment, development of the chassis of a multifunctional comprehensive launch vehicle was conducted by joint efforts among the engineering and technical personnel of the Ground Support Equipment Research Institute as well the Qinghua Machinery Plant in Changzhi, Tai'an Diesel Engine Plant, Tai'an Motor Vehicle Parts Plant, and Hanyang Motor Vehicle Plant; the development pursued in China under the conditions of the absence of satisfactory heavy vehicle chassis in China, for the time being. Successively, trial manufacturing and experiments of vehicle chassis and half-hooked 10 x 10 and 8 x 8 trains were made. Thus, technical breakthroughs were obtained that spurred China's heavy-duty motor vehicle industry, to a certain extent.

In the breakthroughs of these key techniques, the engineering and technical personnel did their best in developing ground support equipment. After more than two decades' efforts, some personnel even lost their lives. To enhance ground support equipment performance, to perfect the complete-set facilities of launch sites, Liu Yuan of the Ground Support Equipment Research Institute actively organized the research and development teams for ground support equipment, organized the attack against technical bottlenecks, and did a lot of work.

Section 4. Ground Measurement, Testing and Launch Control Equipment, as well as Flight Tracking Systems

Ground measurement, testing and launch control equipment is specialized equipment used to measure, test and inspect onboard equipment in the rocket and for rocket launching. Equipment of a

flight measurement system is specialized equipment used to monitor rocket flight status and the operational status of various rocket systems. For the tracking of rocket flight, there are external and interval trajectory tracking modes: in the former case, mainly the rocket flight speed, acceleration, and orientation coordinates are tracked; in the latter case, in general the operational conditions are tracked on commands to control the rocket flight orbits issued by the rocket control system, and the various rocket systems. Through a radio system, the signals are transmitted to ground; therefore, this is also called a remote tracking system.

(A) Ground measurement, testing and launch control equipment

Ground measurement, testing and launch control equipment can be used in detailed and overall examination of the equipment circuitry in the rocket; moreover, preparations for rocket launch factors are made at the launch site zone. Finally, the launch mission is implemented. Therefore, not only does reliability of ground support equipment directly affect rocket launching, but also the measurement and testing precision and sensitivity affect the performance of rocket onboard equipment, and thorough inspections of the rocket as a whole.

China's earliest ground measurement, testing and launch control equipment followed the Soviet system of P-2 guided missiles; this equipment is carried on trucks. The status, measurement and testing prelaunch inspection and the launch proper proceeded, respectively, at the technical site and the launch site zone. At the technical site, there are monoparametric vehicles and leveling vehicles: a monoparametric vehicle conducts monoparametric measurement and testing of various systems, while the leveling vehicle conducts rocket leveling measurements and tests. In the launch site zone, there are control vehicles, power supply vehicles, and cable vehicles

for conducting rocket vertical measurement and testing and to implement the launch mission. This complete set of equipment relies on manual operation to accomplish various functional measurements and tests. However, all the launch processes proceed automatically after pressing several primary buttons.

With advances in rocket technology, a new topic confronting the ground measurement, testing and equipment was: how to improve precision in measurement and testing, to simplify operational procedures, and to shorten the measurement testing and launch time schedules. In the mid-sixties, major improvements were made of ground measurement, testing and launch equipment by adopting a semiautomatic scheme for measurement and testing by using low-speed machinery and electrical equipment for overall measurement, testing and launch control. Strictly interlocking and highly reliable interrupting relays were used to measure and test the launch control circuitry; electromechanical digital voltmeters were used to measure voltage; all-transistorized electronic digital time and frequency meters were used to measure time and frequency; and automatically insulating resistance measurement and testing instruments were used to measure insulation resistance of cables, among other areas. This set of equipment had complete functions, automatically selected measurement points, and automatically computed, compared, decided and recorded data with high precision and fast rates. The success of this development was a promising step toward automation in China's measurement and testing technology.

In the late sixties, a scheme was adopted to have all-transistorization of ground measurement and testing equipment in meeting the requirements of circuit digitization, component miniaturization as well as automation of measurement and testing. With the control panel as the core, in three large consoles the photoelectric inputting device perforated the measurement and testing program and all messages onto paper tapes attached to the

photoelectric device to be transmitted to all parts of the measurement and testing assembly through message conversion, thus accomplishing all measurements and tests of rocket systems. Finally, with screen display and printout, the measurement and testing parameters are recorded. This scheme of measurement and testing not only has many test points, but also has rapid measurement and test rates and high precision.

For a long-range rocket, the ground measurement and testing equipment passes through two stages: in the first stage, an automation scheme of measurement and testing with program control is adopted; in the second stage, a rocket onboard computer scheme is used in measurement and testing. By using a rocket onboard computer for measurement and testing, not only can the arithmetic calculations and logic operations be accomplished, but many other functions as well, such as automatic conversion, compiling, checking and inspection, thus enhancing measurement and testing efficiency. Integrated type simulation digital converters are adopted for rocket measurement equipment; these converters have high noise immunity, applying automatic checking of zero position of the converter, periodically, and reducing the effect on converter of environmental conditions, thus ensuring measurement and testing efficiency.

In successive implementation of rocket launch missions, the ground measurement and testing equipment sufficiently exhibited its inspection and troubleshooting functions in saving the rockets by detecting key malfunctions on many occasions. Once, in a launch process of a long-range rocket, due to imperfections of ignition circuitry, a rocket motor in the first stage did not ignite completely; on that occasion, two ignited rocket motors were shut off in time because of emergency ignition shutoff circuitry in the ground support equipment, thus avoiding the destruction of the entire rocket. On another occasion, during measurement and testing, it was discovered that there was no

output from the programmed distributor; after this distributor was changed in time, the rocket was launched without a hitch. Otherwise, the rocket would have been unable to conduct programmed turns, the only consequence being self-destruction in the air.

In the early eighties, monitoring equipment was used to make up a unified automatic command network; the monitoring equipment transmits in real time the main operational status and progress of the rocket, as well as the measurement and test parameters of the onboard computer to the command center for displaying and recording; moreover, the communication liaison between the launch site zone and the command center is responsible for the automatic command network. The successive monitoring multiscreen Chinese-character terminal also adopted the microprocessing control technique for better universality. During on-line status of the multiscreen Chinese-character terminals, only a single communication channel of the main processor is occupied; however, one main screen and multiple secondary screens displaying different contents can be linked. When necessary, the number of secondary screens can be doubled or tripled. In April 1984, when China launched for the first time an experimental communication satellite, this set of multiscreen Chinese-character terminal monitoring system precisely displayed and recorded flight parameters of the rocket and satellite, in smoothly accomplishing the mission.

In the ground measurement and testing equipment of Changzheng No. 3, a ground monitor developed by the Xinwei Electronic Equipment Plant in Shanghai was the first application of the measurement, testing and launch control system with a multifunctional minicomputer as the core. The computer has many interfaces (unaffected by surrounding interfaces); and it has high data processing capability; only inputting the already written programs into the computer, the ground and the rocket

onboard equipment can be controlled just by switching on the equipment, for automatically accomplishing the automatic measurement and testing of the onboard rocket equipment and ground power supply system. Moreover, this set of equipment provides flight procedures for the onboard rocket computer, and accomplishes automatic rocket flight control. The measurement and test results as well as automatic flight control of the rocket are transmitted in real-time to the command center with data transfer sets; the command center then transmits these messages to all sites throughout China. This set of equipment is relatively advanced, suitable fo. requirements of large operational volume and complex control process of satellite measurement and testing in the launching of experimental communication satellites.

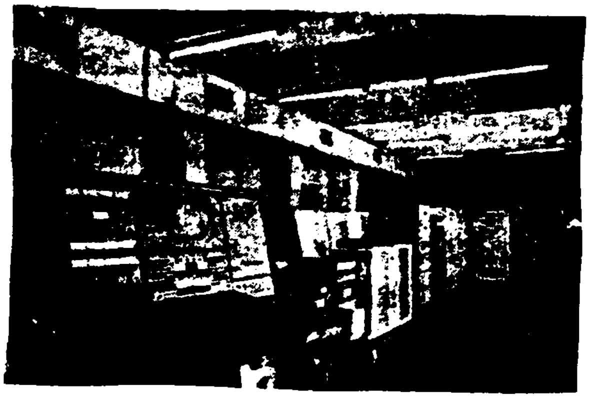

Fig. 108. Ground measurement, testing and launch control equipment for a long-range rocket

(B) Ground support equipment of the remote tracking system

The remote tracking system is a radio multichannel tracking system established on the theoretical basis of multichannel communication to receive radio waves of various remote tracking parameters (among other parameters) transmitted by the rocket and satellite. After demodulation and processing, various

engineering and physical quantities of the measured parameters are obtained.

Over the past three decades, under the leadership of experts Wu Deyu and Shi Changjie of the Remote Tracking Equipment Institute, several types of remote tracking ground support equipment were developed and supplied.

In the early sixties, in coping with China's unique situations, remote tracking equipment was improved and other equipment was imported, thereby doubling the number of tracking channels; this successfully achieved the remote tracking missions in various flight experiments of the intermediate short-range and intermediate-range rockets.

To adapt to the remote tracking parameters, especially the requirements of rapidly increasing numbers of highly-variable parameters, a large-capacity remote tracking vehicle was successfully developed in 1965. These vehicles were a result of major improvements in capacity, system, precision and circuitry technology, thus not only was the communication capacity (capable of tracking hundreds of slowly-varying parameters, tens of highly variable parameters, and time-based parameters) of the remote tracking equipment, but also enhancing measurement precision. Because of the adoption of semiconductor equipment and printed circuit boards, and digital and analog magnetic recorders as the recording equipment, and computers for automatic data processing, the system was greatly simplified with higher reliability. Moreover, a basis was laid for miniaturization of the equipment. Satisfactory measurement and test results were obtained with the equipment during flight tests of Changzheng No. 1 rockets.

To satisfy the requirements of remote tracking systems by means of satellites, starting in 1965 the intermediate low-speed remote tracking vehicle was developed. This set of equipment was

composed of several automatic tracking vehicles, as well as intermediate-speed video-frequency vehicles, and low-speed video-frequency vehicles, among others. By adopting the all-digitized advanced remote tracking system and automatic tracking system, automation of the remote tracking frequency band and equipment was improved.

There are two independent message channels for the intermediate low-speed remote tracking system: the low-speed message channel is used in real-time satellite remote tracking, and the intermediate-speed message channel is used in remote tracking of retransmitted data from a satellite.

The birth of the automatic sensing remote tracking system fills a technical void in China's satellite remote tracking technology by providing satisfactory tracking results of the successive launches and reentry satellites; in addition, the system made contributions to the tracking of long-range rocket recovery compartments for launches into the Pacific Ocean.

To satisfy the requirements of steady development of aerospace activities, beginning in the seventies a comprehensive remote tracking system began to be developed. This system is composed of two major sections on the rocket and on the ground. The rocket onboard portion is the highly variable-speed remote tracking system, with features of high adaptation that is capable of flexible combination of modules based on different user requirements to properly add to, or reduce the number of modules. The ground portion is the y7 series remote tracking system with relatively high capabilities of recording and display, in addition to flexible utilization. In experiments with the comprehensive remote tracking system for launching long-range rockets and underwater rocket launches into the Pacific Ocean, the system exhibited important functions.

To monitor the apogee parameters of a communication satellite, beginning in 1981 improvements were made in intermediate low-speed tracking vehicle, which was installed in a high-seas monitoring vessel with an effective range increased to 40,000 km. In April 1984, this set of equipment successfully accomplished a tracking mission of apogee parameters of an experimental communication satellite.

(C) Ground support equipment of external tracking system

The external tracking system provides a necessary tracking means for rocket flight tests; together with the remote tracking system, the external tracking system provides a reliable basis for analyzing flight testing.

(1) Optical tracking system

China's earliest external tracking equipment used an optical cinetheodolite, which was imported in the late fifties.

Fig. 109. Optical cinetheodolite

In the early sixties, the Changchun Institute of Optical Machines began developing China's first optical external tracking equipment. Under the leadership of the director-professor Wang Daheng, after three years of taxing research the equipment was

adjusted, tested and certified in 1965, recognizing that various performance indicators had reached the design requirements, thus laying a foundation for developing China's optical tracking system.

(2) Laser tracking system

In the early seventies, China's research and development of a laser tracking system began to enter the stage of experimentation. In the eighties, the effective range of laser rangefinders was hundreds of kilometers with a tracking error of less than 10^{-5}. With a laser rangefinder attached to an optical cinetheodolite, the tracking principle changes fundamentally. By using only a set of equipment, the special position of the flight vehicle relative to the tracking point can be computed from the tracking orientation angle, the angle of inclination and the slant distance. This change is a quantum leap of technology in optical tracking equipment.

(3) Radio tracking system

One of the advantages of an optical tracking system is that more items of equipment are not required on the rocket. However, there are also limitations, especially those deriving from meteorological conditions; the mission cannot be accomplished during an overcast or rainy day or days with poor visibility. In addition, the effective range is also limited, to a certain extent.

In 1964, Research Institute Number 10 of the Fourth Ministry of Machinebuilding began to develop a radio external tracking and self-destruct system. The entire system is composed of a continuous-wave radar, a single-pulse radar, a guidance and safety control radar, a computer command instrument, a recording instrument, a unified time station, and communication equipment,

among other items. There are also corresponding items of equipment onboard the rocket for coordination with ground support equipment, such onboard items of equipment as answering machines and receivers. Only four years were spent in the development of this radio tracking system. This tracking system accomplished the tracking of flight orbits of China's Changzheng launch vehicle and orbit insertion projections of the first and second satellites. Later, improvements were made on this technical basis for successful development of high-precision radio tracking systems.

When launching experimental communication satellites, tracking of flight loci of the first and second stages of the carrier rockets can provide safety control information. In addition to the previous tracking systems, China also developed two sets of continuous-wave external tracking systems. In the launch process of experimental communication satellites in April 1984, these two sets of equipment operated normally in obtaining all tracking data required. In addition, there were also developments of advanced station tracking equipment, free-flight sector tracking equipment and high-seas tracking equipment.

In three decades, China built aerospace launch sites of a complete line of equipment and manufactured a large number of ground support equipment items with reliable performance and operational convenience, thus ensuring smooth progress in launching carrier rockets and satellites. Generally speaking, however, the technical level of China's aerospace launch sites and ground support equipment was still lagging behind the advanced countries. In order to advance to a higher stage, new technologies are required and steadily adopted for innovating and improving existing equipment in order to better adapt to the requirements for progress in aerospace technology in China.

CHAPTER TWO: GROUND TRACKING AND CONTROL NETWORK FOR SATELLITES AND GROUND STATIONS

After an artificial satellite carrier rocket is launched from the launch pad, a real-time message link is established with the ground by means of radio waves so that the ground can timely locate satellite position and attitude and the working status of satellite systems, in addition to controlling the satellite to ensure that the predetermined purpose and task of the satellite are accomplished. This is the tracking control of a satellite by the ground, simply called tracking and control. The tracking and control system is an important component part of aerospace technology.

The equipment of tracking and control system generally includes the satellite-bound part and the ground part. A tracking and control ground station consists of tracking and control equipment on the ground, communication, standard time services, computers as well a command and dispatch system, among other items. According to the flight orbit and mission of the satellite, multiple tracking and control stations should deploy on the ground with the control and computation system as the core; a tracking and control fleet should deploy on the high seas. These land and sea facilities constitute a tracking and control network in order to ensure the accomplishment of tracking and control mission for satellite flights.

Besides a geostationary satellite or other high-orbit satellites (including deep-space satellite probes), generally the intermediate low-orbit satellites with relatively large angle of inclination fly over vast areas; therefore, some tracking and

control stations should deploy strategically in key areas overflown by the satellite, such as, the point that the satellite enters its orbit, powered orbit transfer and reentry sector, besides the control computation sector. Considering that most areas on the earth are occupied by oceans, the control and tracking fleet can flexibly station itself on the vast oceans or other bodies of water. Hence, the high seas tracking and control fleet is also an important component part of the tracking and control network. Moreover, based on tracking requirements for different satellites flying in different orbits, mobile tracking and control stations should deploy on the ground to move to the assigned points according to mission requirements for executing the tracking and control mission.

The various tracking and control stations (including the vessel fleet and vehicle fleet) constitute an entity, the ground tracking and control network. Responsible for information exchange in this network, the data processing center is the control computation center, which is the nerve center of the tracking and control network, and applies the unified information control and management at the several tracking and control stations to collect tracking data of the stations for computation, to predict satellite orbits, to track satellite operational status, as well as orders the related tracking and control stations to control satellites or to input data according to requirements.

China's tracking and control network began to be planned in 1965 and began to be built from late 1967. This is an engineering project with highly technical requirements, of enormous difficulties, of long construction cycle, and of high costs. Many engineering and technical personnel, cadres, as well as Liberation Army commanders and soldiers in China were engaged in construction of this important project. In the early construction period of the tracking and control network, the

tracking and control missions of the first and second artificial satellites were smoothly implemented. Successively, the crude scale of the ground tracking and control network of intermediate low-orbit satellites was further expanded and improved, to smoothly accomplish the tracking and control mission of reentry type satellites. In the late seventies more advanced microwave tracking and control equipment was developed on the existing technical basis in China to establish a better control computation center and to set up the tracking and control network for the launching of geostationary satellites. In 1984, a series of complex long-distance tracking and control missions was smoothly accomplished in orbit transfer, attitude adjustment, point fixation, and control of China's experimental communication satellite.

Section 1. Ground Tracking and Control Network

After the first artificial satellite of the USSR was launched in October 1957, China's astronomers began observations of artificial earth satellites. Under the leadership of director Shang Yuzhe of the Purple Mountain Astronomical Observatory, an artificial satellite motion theory laboratory was founded from 1957 to 1958. Moreover, artificial satellite observation stations were established at Beijing, Nanjing, Guangzhou, Wuhan, Changchun, and Shaanxi for observation by using wide-angle telescopes and to conduct experiments of the shortwave band radio doppler tachymetry and orbit fixation. The orbit prediction method of artificial satellite was studied by the Purple Mountain Astronomical Observatory to collect and distribute data from the artificial satellite at various locations for orbital prediction.

In early 1965, according to instructions from premier Zhou Enlai and vice-premier Nie Rongzhen, the Chinese Academy of Sciences organized a team led by Wang Daheng and Chen Fangyun to discuss the problems of founding the satellite ground observation

network. In July 1965, in a proposal by the Chinese Academy of Sciences to the specialized commissions of the central government about a planning scheme for developing Chinese artificial satellites, it was suggested that China's artificial satellite tracking and control system should rely mainly on radio tracking and control together with optical observation. At a seminar on the scheme of China's first artificial satellite convened in the fall of the same year, it was proposed that the satellite tracking and control network should be composed of a control computation center and several ground tracking and control stations with the main missions as follows: (1) receiving and recording of remote tracking data and transmission to the control computation center; (2) computations are performed on the basis of obtaining the initial orbits from orbit tracking and prediction, global prediction of satellite ground locus; (3) the control computation center interprets and computes all data of tracking and control stations for the real-time display of the functional status of the satellite with appropriate decision-making; and (4) through the ground remote control, remote control commands are transmitted to the satellite to control satellite systems.

Considering that the tracking and control network is on a large scale, is highly systematic and comprehensive in its interpretive scope, it is required that the network should have timely and accurate tracking of the satellite. At the beginning, in planning the tracking and control network to make adequate use of China's territory, stations were established in the western, southern, and eastern portions of China so that the control computation center was set up at Weinan in Shaanxi Province.

In April 1966, the Chinese Academy of Sciences was assigned by the National Defense Science Commission the responsibility for planning, designing, construction organization, management as well as maintenance and repair of the ground observation system

for satellites; moreover, missions were clearly assigned to the Ministry of the Electronics Industry as well as the Posts and Telecommunications Ministry, the Signal Corps of the Liberation Army, Jiuquan launch site, the Navy and the Air Force. Successively, the Chinese Academy of Sciences convened a seminar on schemes of a ground observation system for China's first artificial satellite in determining the scheme and the preliminary division of labor of the ground observation system for satellites.

To strengthen the construction of the ground observation system, the Chinese Academy of Sciences began preparations for the founding of the Satellite Ground Observation System Bureau to be responsible for planning, general equipment layout, construction and administration of the ground tracking and control network. Moreover, it was decided to transfer technical personnel and cadres from the Southwest Institute of Electronics, the Automation Institute, and the Huabei Computer Institute, among other units, to organize the "701" Engineering Division to be responsible for preparation of the system.

Not long afterwards, owing to the severe impact of the Cultural Revolution, the general layout design and construction of the satellite ground observation system was transferred to the Experimental Base of the National Defense Science Commission; the base was constructed under the jurisdiction of the Sixth Experimental Department. In March 1967, a scheme reviewing conference was convened for the satellite ground observation system; partial modifications were made to the previous scheme of the observation system. Thus, site selection and the construction preparations began for these stations. In the spring of 1967, tracking and orbit prediction experiments were conducted on satellites launched abroad by using simpler doppler tachymeters at Beijing, Nanjing, Shanghai, and Wuhan in proving

that the basic methods of using doppler tachymeters for orbital tracking of intermediate low-orbit satellites was feasible.

To build the first-stage project of China's satellite tracking and control network, large numbers of technical cadres were brought together from experimental bases at the capital and the northwest Gobi Desert, beginning from 1967. There were technical personnel who had been engaged in ground launch, tracking and control of rockets and missiles for many years, as well as scientific and technical personnel from the Chinese Academy of Sciences engaged in radio tracking and computer tasks for many years. They assembled at Weinan in Shaanxi Province deep in the interior of China; many of them left Weinan to prepare the construction of various tracking and control stations, thus beginning the construction of the tracking and control network in China.

According to the planning of the tracking and control network, the Sixth Experimental Department of the Experimental Base of the National Defense Science Commission decided to build the network in different stages. In the first stage of the project, it was mainly to cope with the requirements of tracking and control of the Dongfanghong No. 1 Satellite, to build seven tracking stations, including four major stations and three intermediate stations. Since the communication links and other accessories were difficult to be completed within a short time, the control computation center stayed temporarily at the launch site when executing the tracking missions for the first and second satellites; only afterwards was the control computation center moved to Weinan.

Included in the first stage project are six subsystems in the ground observation and tracking system.

1. Tracking and orbital prediction system

By adopting the means of mainly radio and secondarily of optics, the system includes 154-IIB single-pulse precision tracking radar, 701-5 passive guidance radar, doppler frequency shift tachymeters, phase tracking interferometers, and wide-angle telescopes.

The 154-IIB single-pulse precision tracking radar was developed by the No. 1014 Institute of the Ministry of the Electronics Industry. When executing the Dongfanghong No. 1 mission, this radar was installed at the Shaanxi station (the major station for orbital insertion point) and the Jiuquan launch site (with its secondary assignment being tracking the powered sector).

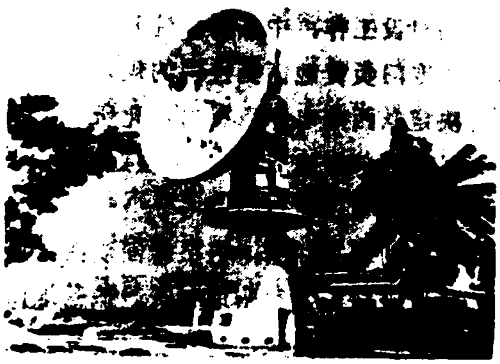

Fig. 110. External view of microwave unified system and its machine room

The 701-5 passive guidance radar guides the above-mentioned precision tracking radar to capture the target; the 701-5 radar was developed by the Xi'an Institute of Radio Technology of the Space Technology Academy.

The doppler frequency shift tachymeter was developed by the Institute of Space Physics of the Space Technology Academy; the Institute was transferred to the jurisdiction of the Chinese

Academy of Sciences in 1979; these tachymeters were built by the Shanghai Scientific Instruments Plant. Engineers Zhu Aikang and Zhou Liqi of the plant took part in the design and development for several models of the doppler dual-frequency tachymeters, which were effective in executing several tracking and control missions. This equipment was also installed in four stations in south China, capable of executing pooled observations of three stations in order to acquire data of first orbits. Tachymeters were installed at Xinjiang station for acquisition of tracking data of the second pass of the satellite over China in order to revise orbital data.

Phase tracking interferometers (in two sets) were developed at the Beijing Astronomical Observatory of the Chinese Academy of Sciences. One set was installed at the Guangxi station and one set at the Xinjiang station for tracking the satellite orbital insertion point and its second pass over Chinese territory.

2. Remote tracking system

The common receivers for Dongfanghong music and remote tracking signals for the first satellite adopted the Chinese-made model 56 receiver used in shortwave communication with the attachment of music and remote tracking demodulation equipment. The common model 56 receiver for long and short distance remote tracking signals for the second satellite was attached to a special remote tracking demodulation equipment; the demodulation equipment was developed, respectively, at the Beijing Institute of Control Engineering and the General Design Department of Flight Vehicles.

3. Standard time reporting system

By applying shortwave means of time reporting, the system receives signals of China's shortwave standard time signal

broadcasting stations (BPV and BPM) to unify the time standard of the several stations.

4. Data processing system

At large stations, data processing computers as well as monitoring, control and recording equipment were installed. Model 717 computers were used for data processing and computation; these computers were developed by the Computer Institute of the Chinese Academy of Sciences. At intermediate-size stations, doppler equipment was installed between the tracking equipment and the data transmission equipment in order to match the data transmission speed.

5. Communication, command dispatch and data communication system

By adopting the communication system mainly of the wire type, and secondarily of the radio communication type, and to meet the demand of the first-stage project of the ground tracking and control network, six types of data communication equipment were developed by the Ministry of Posts and Telecommunications, including four types of wired carrier circuit equipment, and two types of shortwave communication equipment. Moreover, model SCA-3 data transfer sets developed at Qinghua University were adopted. At the control computation center and various stations, command dispatch consoles were installed to execute command dispatch of other stations in the tracking and control network and equipment of subsystems in the same station wired via communication circuits.

6. Control computation center

The center is the heart of satellite ground observation and tracking system, responsible for the command and coordination of

the entire ground tracking and control network. The control computation center has the following items of equipment: data processing computer, monitoring control and display equipment, and communication and standard time reporting system equipment. Among the items of equipment, the data processing computer was the model 108B computer using germanium transistors; the computer was developed beginning in 1966 by the Institute Number 1015 of the Ministry of the Electronics Industry.

When the various types of ground tracking equipment were developed at an urgent pace, civil construction of the tracking and control stations also progressed across the board. Civil construction of the various tracking and control stations included construction of roads, building of a power transmission network, laying of communication lines, precision surveying of the geodetic coordinates of the stations, and various construction projects to meet equipment requirements. After installation, adjustment and testing of various items of equipment at the station, flight calibration tests aboard an aircraft were conducted. From late 1967 to 1970, within a period of less than two and a half years, a ground observation network meeting the initial requirements of a ground observation network for tracking the first batch of artificial satellites was built. During the construction, the builders of these stations overcame difficulties in smoothly accomplishing their mission of station building.

On 24 April 1970, for the first time the tracking and control stations were tested on the occasion of launching China's first satellite. When the launch commander issued the ignition order, the tracking and control stations near the rocket's powered trajectory sector and near the orbital insertion point of the satellite were ready; personnel in the dispatch room intently listened to satellite data capturing and tracking reports transmitted from the stations. Under attention and monitoring by

ground tracking stations, the satellite flew in its predetermined orbit.

Based on the prediction made by the tracking and control network, the Central People's Broadcasting Station and newspapers in the Chinese capital broadcast and reported the time, as well the arriving and leaving orientations for the Dongfanghong No. 1 satellite passing over the world's major cities, so that people around the world could observe China's satellite and listen to music and signals from the satellite based on its broadcasting information.

Less than a year afterwards, on March 3, 1971, China successfully launched its second satellite; precise data were obtained by single-pulse precision tracking radar in the tracking and control stations. Orbital data were quickly obtained by tracking from a single station. Moreover, this further proves that it is economical and effective to use tachymeters as orbital tracking equipment for a satellite. In executing the tracking mission of the second satellite, the Shijian No. 1, several years' observation and tracking were conducted for this satellite using remote tracking equipment of the tracking and control station, thus obtaining a large amount of data.

On the technical foundation laid in the advanced engineering stage of the ground tracking and control network, in the mid-seventies more than ten satellite tracking and control ground stations were built in China with the Weinan control and computation center and the master communication station as the core, thus forming a relatively complete tracking and control network for China's intermediate low-orbit satellites.

(A) Formation of tracking and control network for reentry satellites

Based on the general scheme of China's reentry satellites, these satellites were launched from the Jiuquan launch site; in the operational satellite orbit, its angle of inclination was approximately 70° and the reentry zone was in the Sichuan basin. It is required that a satellite orbit should be readily tracked upon satellite entry into the orbit; moreover, each time when the satellite entered the space over China, control can be executed for inputting data, monitoring and tracking the orbit, as well as the system operational status. Before reentry, the operational status of the satellite should be known in addition to transmitting and receiving commands. From reentry preparation of the satellite to its arrival at the landing point, there are always tracking stations for relay tracking of the satellite in order to predict in advance the reentry landing point.

A reentry satellite has higher requirements on the ground tracking and control network, not only since it requires satellite tracking and orbital determination, but also to execute control. It is required to build a tracking and control network on a preliminary scale before the completion of a series of tracking and control missions: satellite insertion into orbit, operation and reentry. Hence, on the technical basis of seven completed stations in the first stage, four stations (including Weinan) in the second project stage began construction. Moreover, the advanced stations, activity stations and reentry stations were built. On the technical basis of the above-mentioned tracking and control stations for reentry satellites, technical resources of other tracking stations (nonsatellite tracking and control ground stations) should be fully utilized to form a tracking and control network for reentry satellites.

The South China stations are responsible mainly for tracking the orbital insertion sector of the satellite.

For the tracking of the satellite orbital flight sector: after concluding the second-stage of the engineering project, China's stations can ensure that at least one or two stations can track the satellite orbit every time the satellite passes over China. The orbital tracking of the satellite's second revolution is the most important, because thereafter the satellite will not pass over China until several more revolutions; therefore, the satellite's orbit should be precisely tracked during the second revolution in order to determine the satellite's operational status and to compute the time calibration. In addition, the orbital tracking as well as remote tracking and control of the satellite in the last revolution before reentry are also very important; orbital prediction should be made in order to make good preparations for satellite recovery.

This is a mobile team for the recovery station installed in the recovery zone. Based on the orbital situations after satellite launch, station equipment and personnel arrive at the predetermined reentry point; moreover, they are searching for the target according to the predicted reentry orbit and the predicted landing point.

The activity station is a mobile ground station with most of the equipment truck-mounted. According to mission requirements, the trucks move to the appointed spot for mission execution. The activity station can be mobile according to different satellite missions for setting up the stations. The tracking and control personnel and their truck fleet of the activity station go everywhere, even the Gobi desert with its sandstorms and flying stones, or the hilly regions with mountains here and there. People familiarly call them a wagon train on the aerospace route.

Besides, there are some tracking stations outside the satellite tracking and control network; these stations can take

part in activities when necessary to accomplish the satellite tracking and control mission in a joint effort.

(B) Mission of the tracking and control ground station as well the main reentry satellite systems

Satellite recovery includes the following main missions for the tracking and control station: (1) tracking and observation of the satellite in addition to data acquisition; (2) data processing, computation of the initial orbit, revising of the initial orbit, computation of the precise orbit, making predictions, computation of time revisions, selection of recovery circle, prediction and issuing of recovery attitude adjustment, time of separation command, and crude landing point; (3) reception and processing of the remote tracking data, as well as real-time processing for some of the parameters; (4) issuing remote-control commands to the satellite in order to control (on or off) some of the satellite equipment, and to calibrate timing apparatus in the satellite; (5) based on two factors (orbital life and remote tracking parameters), determination of the satellite as to whether or not it should be recovered on an emergency basis, as well as to execute the safety control mission during the orbital flight sector; and (6) during the satellite recovery sector, accomplishment of the following missions: reentry control, tracking observation, computation of reentry trajectory, safety determination and safety control.

The tracking and control station has the following operational systems.

1. Tracking and orbital determination system

The model 154II-B single-pulse precision tracking radar as well as model 701-5 passive guidance radar, and double-frequency doppler frequency-shift tachymeter are used.

The first two items of equipment are used in the first stage of the engineering project; the double-frequency doppler frequency-shift tachymeter replaces the single-frequency doppler frequency-shift tachymeter in the first stage of the engineering project. To improve the orbital determination precision in the frequency-shift speed tracking method, two highly stable frequency message standard sources (with a certain ratio between the two) are adopted in the satellite; the double-frequency frequency shift tachymeter is used on the ground for determination of frequency shifts. Moreover, according to the doppler frequency-shift data at the related frequency, the refraction effect in the ultrahigh-frequency band due to the ionosphere is modified. As proven in practical applications, the precision of orbital determination is relatively high. Therefore, this equipment is installed in the stations used as means for preliminary determination of intermediate low-orbit satellites. This equipment was developed by the Xi'an Institute of Radio Technology, and built by Taihua Scientific Instruments Plant.

2. Remote tracking system

The system includes the real-time remote tracking system and the time delay remote tracking system. The real-time remote tracking system is a low-speed encoding remote tracking system for real-time transmission of operational status and measurement parameters of satellite systems. Utilizing the satellite-bound magnetic tape device, a time delay remote tracking system records the remote tracking data outside of the tracking range of China's tracking and control stations. When the satellite passes over China's tracking and control stations and within their activity range, the magnetic tape device plays back the remote tracking data, which was sent to the ground station via a transmitter. Since the playback speed is many times faster than the recording

speed, an intermediate-speed encoding remote tracking system is adopted. These two types of remote tracking systems were designed by the Remote Tracking Equipment Research of the Seventh Ministry of Machinebuilding and were built by the Bashan Instruments Plant, as one of the main items of equipment in the second-stage engineering project of the tracking and control network; the equipment was installed in the stations before and after 1972.

Fig. 111. Double-frequency remote tracking antenna on the Yuanwang tracking ship

3. Remote control system

Remote control commands and input data are transmitted in the encoded form. As one of the main items of equipment in the second-stage engineering project of the tracking and control network, the remote control equipment successfully accomplished the missions of the command control and data input, beginning with China's third satellite to the mid-eighties with the operation of the intermediate low-orbit satellites.

4. Electronic computers

Since there are large volumes of tracking and control data in the satellite recovery mission, the real-time control requirements are relatively high; the previous model 108B computer is incapable of meeting these requirements. Therefore,

the model 320 computer system was developed by Institute No. 1015 of the Ministry of Electronics Industry. This computer system executes the main computation mission in the process of satellite launches, operations and recovery, in making a contribution to the aerospace activities.

In the mid-seventies, with joint efforts of related units throughout China over a period of more than four years, the various kinds of tracking and control equipment developed in China were successively installed, adjusted and tested at ground stations; flight calibration tests were conducted. Thus, a preliminary-scale tracking and control network for the intermediate low-orbit satellites was set up, in creating the necessary conditions for launching and recovery of various satellites in the intermediate low-orbit class in China thereafter.

(C) Tracking and control network of China's nonrecoverable satellite operating in intermediate low orbits

China's nonreentry satellites operating in intermediate low orbits are generally similar to reentry satellites. Based on different missions, there are slight distinctions in station makeup and equipment used. The main distinction is the combining of double-frequency frequency-shift tachymeters and the remote tracking equipment.

In 1970, when discussing the equipment installed in the ground tracking and control network during the second-stage engineering project, decisions were made on the problem of standardizing tachymeters and remote tracking stations for the mission of nonreentry satellites. The full utilization of radiofrequency channels is the developmental trend of space electronics technology. The following advantages exist, by combining the antennas (including satellite-bound and ground

antennas), transmitters, receivers and modem equipment are energy-sparing, jamming reducing, lowering the number of items of equipment, and lessening the workload for operation, maintenance and repair. Although this is the first step toward the full utilization, the advantages of economic and technical benefits thus realized are self-evident. This comprehensive radio equipment for remote tracking and the double-frequency frequency shift tachymeters are used in launch missions of China's Shijian No. 1, Shijian No. 2 and the other nonreentry satellites, thereby smoothly accomplishing the missions. This equipment was developed and built by the Xi'an Institute of Radio Technology and the Taihua Scientific Instruments Plant.

After China's first long-wave time reporting station, the Pucheng Astronomical Observatory, was built and developed the time reporting services, a very advantageous condition was created for time synchronization of China's tracking and control network. Previously, China had utilized signals of the following long-wave time reporting stations for time synchronization, along with time reporting by wired transmission. Moreover, cesium beam atomic clocks were used for precise time synchronization among the various stations.

Section 2. Tracking and Control of Geostationary Satellites

On April 8, 1984, China successfully launched a geostationary experimental communication satellite; its functional range of China's ground tracking and control network also extended to a new height, 35,786 km, in the geostationary orbit.

(A) Microwave standard reference system

In late 1971, the Chinese National Defense Science Commission organized the related departments to discuss a

conceptual scheme of China's tracking and control system for communication satellites. At that time, the second-stage engineering project of the ground tracking and control network was fully underway; the tracking and control network for intermediate low-orbit satellites was about to be completed. On this technical foundation the tracking and control equipment for high-power, high-sensitivity and ultralong-range should be expanded in order to satisfy the tracking and control requirements of the geostationary satellites. Therefore, two systems were proposed: (1) scattered tracking and control system and (2) microwave standard reference. In the former case, microwave tracking equipment with the addition of ultrahigh-frequency remote tracking and remote control; the various functional systems are independent of each other. In the latter case, the multiple functions are unified into a single set of equipment with the adoption of microwave frequency bands.

To decide upon the selection of one of the two above-mentioned schemes, supervised by the chief design engineer Chen Fangyun of the Satellite Communication Engineering Tracking and Control System, from 1972 to 1973, the Tracking Communication Institute of the National Defense Science Commission conducted large volumes of investigation, study and coordination. After repeated discussion and verification, the various circles shared the view that the adoption of the microwave standard reference system for tracking and control of geostationary satellites is economical, effective and technically feasible.

In this scheme of the microwave standard reference system in China, for orbit tracking the following systems are adopted: dual-direction frequency-shift speed tracking system of upper and lower carrier coherence, the ranging system of pseudo-random code with the addition of sound ranging, and a goniometric measuring system in the form of single-pulse radar were adopted. For subcarrier modulation, remote tracking totally occupies two

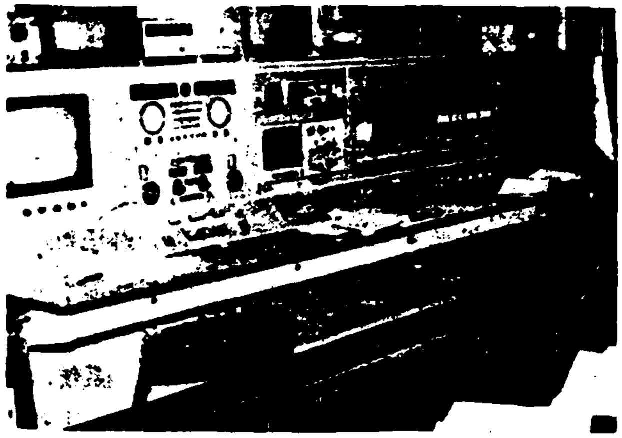

Fig. 112. Model 420-2C main control console of the microwave standard reference system

subcarriers, in the descending carrier with subcarrier modulation: the encoding remote tracking subcarrier and the simulated remote tracking subcarrier. In the former case, it transmits various satellite parameters; in the latter case, it mainly transmits the attitude parameters. As a subcarrier, the remote control is modulated on the ascending carrier. To implement data transmission between tracking and control stations, data transmission subcarriers are modulated at the ascending and descending carriers.

Composed of a satellite and a complete set of receiving and transmission equipment, a microwave standard reference system has capabilities of tracking and orbital determination, remote tracking, remote control and digital transmission. Then laymen generally call it a four-in-one system; this is a major radio engineering project. Decided by the National Defense Science Commission, one set each of this system was developed by the Fourth and Seventh Ministries of Machinebuilding. Led by Ren Xinmin, Zhangluqian, and Liu Tiechang, the number 450 engineering office organized the related factories and institutes of the Seventh Ministry of Machinebuilding to develop the microwave

standard reference system. The project deputy general design engineer Zeng Yiduo supervised the development of ranging and tachymetry systems. The Number 1010 Institute of the Fourth Ministry of Machinebuilding developed another set of the microwave standard reference system with the code name, 155 engineering project. In 1976, a satellite communication project technical coordination team was established by the National Defense Science Commission. Led by professor Chen Fangyun and other related experts, they were responsible for coordinating the related problems of ground tracking and control system, satellites, and carrier rockets.

The complete set of equipment for the microwave standard reference system adopts nearly 200,000 components of semiconductor devices and integrated circuitry, among others. The complete set of equipment is installed in more than ten machine rooms with a total floor space of more than 1000 square meters. The equipment is high in reliability and convenient in operation. Compared with similar equipment abroad, the successful development of China's microwave standard reference system with generally corresponding technical performance as systems made abroad is a milestone in technical development in tracking and control of China's satellites.

(B) Tracking and control network of geostationary communication satellites

From launch to the final fixation at a predetermined space site, a communication satellite should pass through multiple procedures from orbital change to orbital adjustment.

After entering the transfer orbit, a satellite has the following tracking and control missions: (1) tracking the satellite orbital data (parameters of transfer orbit) after separation of satellite from the carrier rocket; (2) remote

tracking and monitoring of the operational status as well as the other parameters (attitude and speed of revolution, among others, of the satellite; and (3) control of the satellite, including the establishment of ignition attitude and ignition control.

After entering the quasi-geostationary orbit, a satellite has the following tracking and control missions: (1) before the satellite is out of the effective range of a ground tracking and control station, the quasi-geostationary orbital parameters are tracked; (2) applying remote tracking and remote control of the satellite to establish an orbital normal direction attitude for the satellite; and (3) applying the orbital adjustment and control. First, the satellite is allowed to drift toward the predetermined position; based on design requirements, the satellite should drift toward the predetermined position upon entering the quasi-geostationary orbit; however, if there is deviation, orbital adjustment is made. After the satellite arrives at the predetermined position, orbital adjustment is made to allow the satellite to enter the synchronizing fixed point (stationary) orbit; thus the satellite stops drifting. At that time, the revolving cycle of the satellite is close to the cycle of earth's rotation (4 minutes' difference).

After fixing the satellite in the geostationary orbit, it has the following tracking and control missions: (1) periodic tracking of orbit; when the orbital position is deviated by a predetermined value, orbital correction is made; (2) tracking the satellite operational status and controlling its operational status; (3) tracking and adjusting the satellite attitude and speed of revolution; and (4) tracking of the ground orientation status of the spin-eliminating fixed-directional antenna.

To accomplish the above-mentioned missions of tracking and control, the Weinan and Minxi stations are mainly relied on because the microwave standard reference system has been

installed in them. However, the carrier rocket sends the satellite into a transfer orbit, which is above the equator in the South Pacific; therefore, the ground tracking and control stations in China are unable to track the first revolution of the transfer orbit. Therefore, the high-seas tracking fleet should be mobilized. Besides the tracking of the carrier rocket in its powered sector, the shipboard remote tracking demodulation equipment and the double-frequency automatic tracking remote sensing system for descending signals of the satellite microwave standard reference system can be received, capable of tracking the first revolution of the satellite transfer orbit.

Both the Weinan and the Minxi stations can track and control the apogees of the second, fourth, sixth, ninth, eleventh, thirteenth, and so on satellite transfer orbits, as well as most orbital sectors nearby. Since the microwave standard reference system adopts a parabolic antenna with a 10 m diameter, the wavebeam width is smaller than 0.5°; thus a wide-wavebeam radar is required for guidance. Therefore, the Space Technology Research Institute and the Taihua Scientific Instruments Plant developed an automatic tracking guidance radar with a 2.8 m diameter antenna to be used as the guidance equipment for large ground antennas of the microwave standard reference system.

When a geostationary satellite with stable spin attitude makes orbital or attitude corrections, it is required that jetting of small rockets in the satellite should be synchronized with satellite spin; this is synchronization control. The synchronization control for China's communication satellites adopts large-loop synchronization control. In other words, the satellite spin cycle, the spin instantaneous phase, and other attitude parameters can be tracked by remote sensing. Commands are issued through remote sensing to have the phase of the jetting pulse of the satellite rocket engine precisely corresponding to the satellite spin phase. Time precision of

synchronization control should be less than 1 ms; there are strict requirements on transmission, modulation and demodulation of the tracking and control loops.

The tracking and control network for communication satellites includes ground tracking and control stations to the far-off tracking fleet in the South Pacific with a very responsible mission in communication and data transmission. In command and dispatch, unified coordination should be made among the launch site, control and computation center and the tracking fleet. Therefore, multilevel dispatch and command systems centering on the command post of the National Defense Science and Engineering Commission was formed.

From launch to point fixation of communication satellites in orbit, vast volumes of signals required real-time processing. For this mission, tens of computers of the tracking and control system were connected through communication lines, in forming a computer network of the tracking group. In an experimental mission, the vast number of computers required for participation and networking brought China's computer networking and computation to a new level.

(C) The mission was accomplished victoriously.

The Beijing command post was brightly lit on the night of April 8, 1984, giant television projection screens in the command and dispatch room displayed the launch site situation at the rate of little more than 30 seconds per frame.

At 19:20 hours the rocket was ignited. The tracking and monitoring stations tracked the target on time; as displayed on the command post screens, the real-time loci of the carrier rocket matched the predetermined loci. In 20 minutes, as shown by data transmitted from the high-seas fleet, the carrier rocket

had sent the satellite into the predetermined transfer orbit. The satellite should fly more than 5 h from entering the transfer orbit to its arrival at the apogee of the first revolution. At that time, one ship of the high-seas tracking fleet sailed for 5 h toward the northeast in order to receive the satellite remote tracking data at the apogee of the first re' 'lution transfer orbit,

Fig. 113. Model 450-1 shaft rotation angle encoder

Tracking control at the second revolution of the satellite transfer orbit is very critical. Many tracking and control missions of entry into the quasi-geostationary transfer orbit should be conducted within the observation arc sector of this revolution. The Minxi and Weinan stations in China conducted a target search based on the prediction from the orbital parameters tracked at the orbital insertion point; when the satellite just emerged from the horizon, the guidance instruments immediately captured the target and the microwave standard reference system successively and quickly captured the target. Although at that time the satellite-bound antenna direction was not aligned with the ground with relatively weak signals received; however, the

ground station could still reliably apply tracking and monitoring to the satellite with acquired data more precise than predicted. All commands transmitted to the satellite were error-free following verification by remote sensing. Nearly 10 h of continuous tracking was conducted up to the second revolution of the transfer orbit. Observations inside China were unable to reach the third revolution of the satellite transfer orbit. The fourth revolution is the revolution when the rocket positively ignites at the apogee. Before ignition, tracking and sensing of the orbit was again conducted; moreover, precise adjustment of ignition attitude was made. At 08.47 hours on April 10, the ground station issued an ignition to the rocket at apogee to allow the satellite to enter smoothly the quasi-geostationary orbit. By tracking of the satellite orbit by the ground station, it was predicted that the satellite would drift to the predetermined position (over the equator at 125^{o} E. Long.) on April 16. After the satellite was fixed at a space point, the following was smoothly accomplished: establishment of communication attitude, as well as tracking and control missions of the spin-eliminating orientation antenna.

The ground tracking and control network for communication satellite is a vast engineering project, including a tracking and control center with numerous computers, two microwave standard reference systems with high precision and long-range coverage and three high-seas tracking ships equipped with electronic and optical tracking and sensing units. Moreover, there are radar stations, remote tracking stations and optical tracking stations located in China's vast territory. These facilities activate in coordination to operate harmoniously like a precision-built machine without deviation of a fraction of a second. The various items of equipment were precise and reliable, and the entire system operates smoothly. For developing the equipment of the tracking and control network, Chinese scientific and technical

personnel made a great contribution by pouring their energies in overcoming great difficulties.

In the span of more than a decade, the various kinds of tracking and control equipment required by the aerospace engineering project were developed by reliance on China's own efforts to gradually establish a relatively complete line of satellite tracking and control network, to smoothly accomplish the tracking and control mission of satellite launches, and attaining a relatively high level of tracking and control. With the further development of China's aerospace technology, the current tracking and control system still requires further perfection and enhancement, especially to greatly improve tracking precision, to expand tracking data, to enlarge the range of real-time observation, and to accomplish the tracking and control mission with greater complexity and higher requirements.

Section 3. Satellite Communication Ground Station

The satellite communication ground station is one of five major systems in the satellite communication engineering project.

In satellite communication, a communication network is formed between the satellite and the ground stations to transmit communication signals. Based on locations of communication stations, there are space and earth communication stations (generally called ground stations). The communication ground station is installed on the surface of earth. There are stationary stations, mobile stations (such as stations on board ships) and portable ground stations.

A complete communication ground station includes the six following parts: antenna system, transmission system, receiving system, communication control system, terminal system and power supply system.

Since a geostationary satellite is far away from the ground (about 36,000 km away), there is high signal attenuation. Therefore, large-diameter antennas are generally used; the largest antenna diameter is 30 m, with the adoption of hundreds, even more than 1000 W of high-power transmitters used to send the signal to the satellite. To receive weak communication signals transmitted by a satellite transponder, very highly sensitive low-noise receivers should be installed, in addition to parametric amplifiers of wide frequency band.

The earliest communication ground stations used in China were established for television retransmission on the occasions of President Nixon's and Japanese Premier Tanaka's visits to China in 1972, for communication links with their respective countries. These were portable ground stations with 10 m diameter antennas. By late 1972, China began to make preparations for building a total of three communication ground stations with 30 m diameter antennas at Beijing and Shanghai. In 1973 and 1974, China leased message channels of the Pacific and Indian Ocean regions from the International Satellite Organization to establish an international communication business. Afterwards, China's Ministry of Posts and Telecommunications vigorously engaged in the construction of other communication ground stations.

The successively launching and fixation of special points for China's experimental communication satellites as well as the completion of the coordinate satellite communication ground stations created conditions for experiments and trial operation of satellite communications. China's satellite communication network was systematically planned and gradually constructed according to the principle of full utilization, merger of military and civilian uses, as well as simultaneous handling of communication and broadcasting, in addition to combining with

requirements of satellite communication experiments and communication operations, as well the technical level of ground stations. There are six types of ground stations in operation, including one central station, three local stations and two experimental stations. The largest antenna diameter is 15 m and the smallest is 6.0 m. In addition, there are several small mobile stations on board boats. These ground stations were designed and developed by the following Chinese ministries, Electronics Industry and Posts and Telecommunications.

The Nanjing experimental station was completed in December 1975; this is China's first set of made-in-China ground station. In 1978, the station took part in the Symphony Satellite experiment (a joint development project of France and West Germany). In 1982, the Nanjing station passed certification tests by the International Communication Satellite Organization. The station has 10-m diameter antennas, and has mainly analog system communication equipment, capable of receiving and transmitting one color television channel and a single FM channel sound accompaniment; the station can also receive newspaper type facsimile or 12 to 15 channels of broadcast programs.

The Shijiazhuang experimental station was built in 1976. In 1978, this station conducted communication experiments with the Symphony Satellite. In 1982, the satellite passed certification tests by the International Communication Satellite Organization. The station is equipped with a 15-m diameter antenna and has mainly digital type communication equipment. In China's experimental communication satellite engineering project, the station is responsible mainly for the missions of in-orbit tracking and tests of communication satellites, and certification tests of ground stations. The station can receive and transmit six channels of digital telephone communication, and a single channel of single-carrier telephony. In addition, the station is equipped with time-division multiaddress communication testing

equipment, capable of receiving and transmitting modulating television. On January 29, 1984, after China launched an experimental satellite, telephone and television transmission tests were conducted between Shijiazhuang station and the Beijing communication ground station, in acquiring valuable experimental data and obtained satisfactory retransmission results.

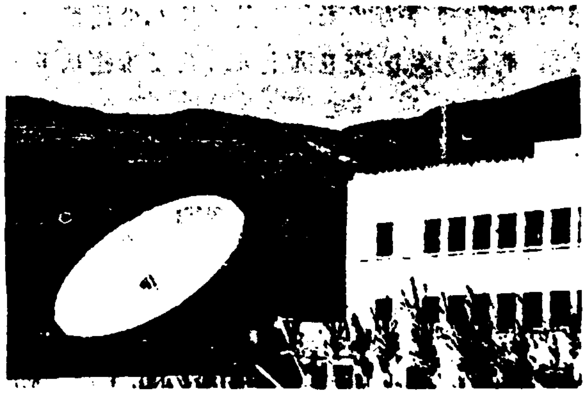

Fig. 114. Satellite communication ground station

Kunming ground communication station was built in 1982, with a 10-m diameter antenna. The station is responsible for experimentation and trial operation of digital and analog system communications, capable of receiving one color television channel and a single channel of FM sound accompaniment transmitted by the Beijing communication ground station; the station can also receive 12 to 15 channels of broadcasts or newspaper type facsimile. In addition, the station can link up with Beijing for two pairs of six-channel digital telephony and one pair of single-channel service digital telephony.

Urumqi communication ground station was built in 1982 with a 15-m diameter antenna. The station has similar business as that of the Kunming station.

The Beijing communication ground station is the central station of the engineering communication system for experimental communication satellites; this is the command station in the

process of experimentation and trial operation, responsible for the transmission of television and broadcast programs of the Central Television Station. In the long-term operations of satellites, the Beijing station is responsible for the use and management of these satellites. The station was built in 1983, having 13-m diameter antennas, responsible for digital and analog system communications. Moreover, the station is also a center of communication operation and management. To major stations having greater than 10-m diameter antennas, engaging in analog system communications, the Beijing station can transmit one color television channel and its sound accompaniment; the station can also transmit and receive 12 to 15 channels of broadcasts, or one channel of newspaper type facsimile. For digital system communication, the station can receive and transmit four pairs of six-channel digital telephony and a single channel of service digital telephony. Moreover, the Beijing communication ground station can link up with marine stations, and it is responsible for broadcasting standard frequency and time. As to communication operation management, the station conducts mainly monitoring of various communication services. To acquire satellite remote tracking data from tracking and control stations, and requesting remote control of satellites by the tracking and control stations, the station establishes the gain level of conventional transponders, and reports satellite status and orbital parameters to the various communication ground stations.

The Lhasa communication ground station was built according to the requirements of the People's Liberation Army Signal Corps, and the Ministry of Electronics Industry, among other units, after the launch of the communication experimental satellite. Utilizing China's communication experimental satellites, the station rebroadcasts the program from the Central Television Station and the broadcast programs of the Central Broadcasting Station; in addition, the Lhasa station makes it possible to have

direct telephone links between the capital Lhasa of the Tibet Autonomous Region and the nation's capital. The Lhasa station was built in September 1984. By receiving and transmitting at the Lhasa communication ground station from the experimental communication satellite, troop reviews and parades on the National Day of 1984 were seen in good time by the Tibetan people.

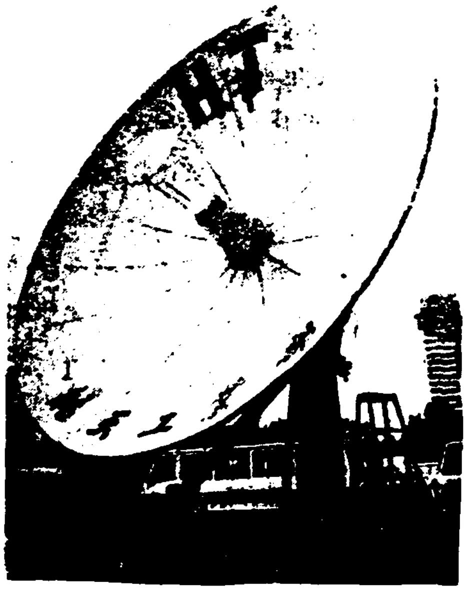

Fig. 115. Small satellite television ground receiving station number 1
KEY: 1. Ministry of Aerospace Industry

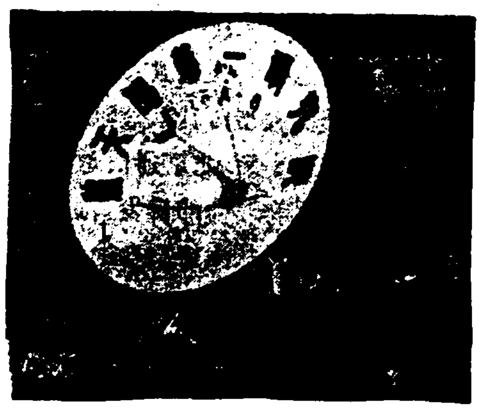

Fig. 116. Small satellite television receiving station number 2
KEY; 1. First Research Academy, Ministry of Aerospace Industry

In the engineering project of the experimental communication satellite, two imported ground stations at Beijing west suburb and downtown Chengdu also took part in networking.

To speed up the pace of television coverage throughout the nation, the 53 satellite television ground receiving stations, as

a gift by the Party Central and the State Council to 16 provinces and autonomous regions in 1985, went on the air; these stations rebroadcast the programs from the Central Television Station. This rebroadcasting has a positive function in developing the economy and in stimulating the people's cultural activities of China's border areas, old revolutionary zones and minority areas.

These satellite television ground stations were contracted to be built by the following ministries: Aerospace Industry, Electronics Industry and Posts and Telecommunications; their construction was supported and coordinated by departments such as of Railways, Aviation, and Air Force.

CHAPTER THREE: MATERIALS TECHNOLOGY AND LARGE EXPERIMENTAL FACILITIES

Raw materials and components are fundamentals of development in aerospace engineering. High-energy fuel propellants generate large thrust in the hundreds or thousands of tons class in order to lift a rocket with satellite to great heights of hundreds or even tens of thousands of kilometers. Rockets and satellites fly in outer space, thus requiring high-strength structures to be adaptable to environmental conditions of high or low temperatures, high pressure, vacuum and/or vibrations. As the nerve center of the rocket and satellite, the control system should handle rapidly varying signals for adjustment of attitude and orientation; thus, highly reliable electronic components are required. It can be said that an aerospace enterprise will find it hard to proceed without appropriate materials and components.

To achieve the expected results, another important sector of aerospace engineering is to solve satisfactorily the ground testing problem. Sufficient ground tests can expose any problem to eliminate all hidden defects or malfunctions prior to flight testing. Otherwise, the task will proceed at low efficiency or even to no avail.

Section 1. Materials and Technology

Levels of materials and technology represent an important measure by which to evaluate a nation's standing in fundamental industry and leading-edge science and technology. Manufacturing technology for rockets and satellites is the crystallization of modern industries.

Like any machine, a rocket or a satellite should be first designed by engineers, then the manufacturing department used materials meeting the design requirements with advanced and rational technical processes in manufacturing. Through sufficient ground tests, inspection and verification of the design as evaluating technical quality, all this can determine whether the general layout design is satisfactory. A rocket or a satellite has thousands or even tens of thousands of parts; some of these parts are under very high stress, and some others function at very high or very low temperatures, while still others operate in highly corrosive media. Different components require different materials and different technical processes in manufacturing. Achievements in aerospace technology are the results of comprehensive application of present-day science and technology; however, materials and technology are the fundamentals of research and development of aerospace technology. In developing rockets and satellites, advanced design concepts play a major role; the advanced manufacturing technology ensures results; and applications of new materials are the basis for these results. These three factors are closely related, complementary to each other. Without new materials, advanced design concepts are difficult to carry out. The advanced design concepts certainly will place new demands on materials, thus promoting advances in materials. To implement the execution of advanced design concepts and adoption of new materials, rational and highly skillful technology is indispensable. To a certain extent, quality levels of materials and technology determine the technical performance of rockets and satellites. Without advanced materials and manufacturing technology as the fundamentals, no advanced rocket and satellite can be built. The developmental process of Chinese aerospace activities well illustrates this point.

Many difficulties with materials and technology were encountered at the beginning stage of China's rocket industry.

Vice-premier Nie Rongzeng paid close attention to materials and manufacturing technology for rockets; he demanded that first acceptable materials be developed in organizing a nation-wide coordination for developing new materials, components and equipment. Under the spur of the aeronautical industry at that time, the development of metal materials was faster in China's production of raw materials and supplies; however, the varieties and specifications were incomplete for these materials. There was a weak linkage between nonmetallic materials and electronic components. Equipment was inadequate to make new raw materials and supplies; many new techniques were still not mastered. Based on the demands of rocket development and under unified state planning, the Chinese Academy of Sciences, as well as the departments of chemical engineering, metallurgy, electronics, machinebuilding, architectural materials, petroleum, textiles and light industry were, respectively, responsible for research and trial manufacture of new rocket fuels, sealing materials, lubricants, high-temperature and high-strength materials, light alloys, electronic components, electrovacuum devices, precision bearings, precision machines, and special nonmetallic materials. For certain items not listed in the five-year plans, vice-premier Li Fuchun insisted on concretely carrying out these items by requesting the related ministries, commissions, provinces and municipalities to include formally these items in the plans in multiple production sites with smooth-running arrangements. By citing examples of metallic materials between 1958 and 1960, the following items were successfully trial-produced: 39 items of ferrous materials, 78 items of nonferrous materials, and 36 items of metallic materials with special physical performance.

In the aerospace industry, the following special materials are often required: very large, very thick, very wide, very thin and very slender. These materials often become bottlenecks in rocket and satellite development. To solve the problem of these special materials, the Party Central decided to develop nine

major items of equipment including 2.5-m steel rolling mills, 12,000-ton hydraulic press, and high-tonnage extrusion machine in order to meet the demands of the aerospace industry for materials production.

To solve the problems of raw materials, supplies, components and fuels for rockets designed in China, large numbers of trial production runs were conducted by the departments of metallurgy, chemical engineering, machinebuilding, electronics, architectural materials, petroleum, textiles and light industry. Successful trial production runs were achieved in a number of high-strength standard steel, high-temperature and high-strength alloy steel, high-strength light alloy and ferrous materials, thus solving the materials problem for the rocket casing, fuel tanks, rocket engine, and satellite recovery devices. The departments of chemical engineering, architectural materials and petroleum provided high-energy fuels and solid composite propellants for rocket engines; in addition, the following nonmetallic materials were trial-produced: various materials for heat insulation, sealing and fiberglass-reinforced plastics. The departments of the electronics industry trial-produced various kinds of electronic components as well as precision instruments and meters. From 1958 to 1985, there were more than 2500 items of new-product trial manufactured, arranged by the electronics industry system.

Required by the systems of the rocket, satellite and ground tracking and control network, there should be many kinds as well as high requirements on quality and reliability imposed on the electronic components and the fundamental products. With the development of transistors to integrated circuits for China's electronic components, inherent reliability was greatly enhanced. For the electronic components used in the aerospace engineering project, there are 15 categories that include about 2000 kinds and tens of thousands of specifications that were distributed

among the more than 300 plants and research units scattered in 25 provinces, municipalities and autonomous regions; each year, the total output was more than 20,000,000 items. By citing the example of a long-range rocket, a rocket and a complete set of ground support equipment require more than 1000 kinds, more than 30,000 specifications, and more than 100,000 electronic components.

To meet the developmental demands of three major engineering projects, especially the satellite communication engineering, the Ministry of Electronics Industry and the related scientific research units and plants under the Chinese Academy of Sciences pooled all their efforts to develop the required new electronic components. The following items were successively developed: low-temperature connectors, ultraminiature relays, high-temperature-proof and radiation-proof installation wires, low-capacitance, low-noise and high-frequency metal film resistors, microwave field effect transistors, and low-frequency and high-frequency transistors, among others. High reliability and long service life are quality requirements imposed on the electronic components by the rocket and the satellite. A rocket or a satellite requires tens of thousands of specifications and more than 100,000 components. The quality of each component can directly affect the reliability of the entire rocket complex; this is an important factor as to whether or not the rocket and satellite launch is a success. In a key component with just a conductor wire or a part showing unreliability, testing could result in a failure, even leading to undesirable consequences. Based on the following experiences, the reliability of components for a rocket is about level 7 to level 8; in other words, the malfunction rate is in the range between 10^{-7} to 10^{-8} per hour. For a satellite, the reliability is level 8 to level 9; in other words, the malfunction rate is 10^{-8} to 10^{-9} per hour. Because of China's weak foundations of industry, science and technology, especially the development of the electronics industry, it is

still difficult to attain the advanced international indexes mentioned above. To solve the reliability problem for electronic components, the Ministry of Electronics Industry did a great deal of work. At the beginning, the assembled-machine research units applied a screening method in selecting outstanding parts to be assembled into the machine. Based on statistics, generally only about 30 to 50% of the parts were qualified. In so doing, two consequences resulted: one is the increased work volume in screening, and the other is the large numbers of parts in the inventory and reject category. After improvement with the implementation of the screening supply method at fixed points by the producing plant, the rate of the screened parts was between 70 and 80% to be assembled into the machine. Since most plants practice the screening of finished products without taking measures from the point of view of the technology, thus the inherent reliability problem with components was not fundamentally solved. After 1978, the quality control and feedback method of seven specials (special batch, special materials, special personnel, special machine, special card, special inspection and special technique) was adopted; thus, the inherent reliability of components was improved considerably. Compared with the conventional components, the malfunction rate of components made under the seven specials approach was one order of magnitude higher, with the qualification rate higher than 90% for assembly into the assembled machine. The adjustment and testing cycle of the assembled machine was relatively shortened, with an appreciable reduction in the malfunction rate. Further improvement and extensive development of the seven specials approach will lay a good foundation for higher reliability of components later on.

At about the same time, technical research was stressed and a number ɔf processing technique problems were solved. Moreover, a series of comprehensive tests were conducted: nondestructive testing, troubleshooting, storage, climate and environment. The

scientific research units, production units and higher institutes and colleges actively took part in developmental work with rocket materials, thus laying a solid foundation for research into new materials, new technologies and new inspection and test methods. According to incomplete statistics, from 1960 to March 1966, altogether 2680 items of new materials were successfully developed and made available for use by the related ministries and commissions (not including the Chinese Academy of Sciences). From 1970 to 1980, another 1360 items of new materials were successfully developed. The Fifth Academy of the National Defense Ministry established cooperative relationships in research with more than 30 units as well as 28 provinces, municipalities and autonomous regions, including the Chinese Academy of Sciences, ministries of various industries, the Ministry of Education, the various general administrations, as well as branches of the armed forces. From 1960 to 1982, 2244 items of cooperative missions were successively arranged, for new materials, new technologies, new components, instruments and meters, and large items of equipment. There were 448 development projects (including fluorine-containing materials, temperature control materials, heat insulating materials, and carbon-carbon materials) in the following institutes under the jurisdiction of the Chinese Academy of Sciences: organic chemistry, Shanghai silicate chemistry technology, Taiyuan coal chemistry, Lanzhou physical chemistry, Dalian physical chemistry, Beijing chemistry, and Shenyang metals. These materials not only satisfy the current demands of aerospace technology, but also provide a material foundation for later developments. There were 395 and 220 items (refer to Table 4) of new materials used for the long-range rocket, as well as the third-stage of the Changzheng No. 3 rocket, and the experimental communication satellite, thus ensuring the development of these key engineering projects.

The development of rocket materials in China began by copying USSR materials. Under the leadership of expert Yao

Tongbin and institute staff member Yu Qiao of the Beijing Institute of Materials Technology, with coordinated efforts by the related research and trial-production units, large numbers of new materials were produced on a provisional basis, thus satisfying demands in scientific research and production.

TABLE 4. Development of New Materials in Two Key Engineering Projects

13 单位：项

	远程火箭用的新材料 11	"长征三号"第三级和试验通信卫星用的新材料 12
冶金工业部 1	88	96
化学工业部 2	129	37
建筑材料工业部门 3	86	9
轻工业部 4	45	4
石油工业部 5	23	5
纺织工业部 6	8	2
中国科学院 7	16	13
机械工业部 8		1
有色金属总公司 9		53
合计 10	395	220

KEY: 1. Ministry of Metallurgical Industry
2. Ministry of Chemical Industry 3. Departments of architectural materials and industry
4. Ministry of Light Industry 5. Ministry of Petroleum Industry 6. Ministry of Textile Industry 7. Chinese Academy of Sciences
8. Ministry of Machinebuilding Industry 9. Non-ferrous Metal General Corporation 10. Total
11. New materials used for long-range rocket
12. New materials used for third stage of Changzheng No. 3 rocket and experimental communication satellite 13. Unit: items

There are more than 800 kinds of cold-rolled steel plates used in large quantities in a rocket. These materials were not well advanced at that time, and the manufacturing techniques were not very complex. However, there was no large cold-rolling equipment in China so these plate materials were not able to be rolled. A trial production mission was assigned to the Fushun

Steel Mill and the Anshan Iron and Steel Corporation. Technicians and workers at the Anshan Steel Mill (under the corporation) innovated a universal steel-rolling machine for rolling 4-mm thick conventional steel plates to adapt to the rolling of 3-mm thick alloy steel plates. Thus, the production requirements were satisfied.

In the trial manufacture of aluminum alloy plates using for rocket casings in China, the yield strength is below the requirements in the specifications. In a joint effort by the Northeast Light Alloy Processing Plant, the Harbin Industrial University, and the Carrier Rocket Research Academy, repeated tests and experiments were conducted to bring the yield strength up to specifications; this is a forward step for products and manufacturing techniques of aluminum alloys and their products in China. Later, based on the carrier rocket feature that it only functions once within a short time, aluminum alloys with higher magnesium content were developed, thus greatly raising the yield strength and solving problems of chemical milling techniques for these materials.

Large numbers of rubber sealing components are required in the rocket engine system, propellant, pipeline valve system, the instrumentation compartment, and the control system, ground transportation and launch system. Specializing in making rubber pipes and rubber belts, the Fourth Shenyang Rubber Plant was assigned the production mission of rocket sealing components. Within a single year, 30 kinds of rubber materials were used to manufacture, on a trial basis, 176 kinds of sealing components with specifications up to, or exceeding the design requirements, thus ensuring progress in copying. When rocket designing was begun in China, eight kinds of rubber seals were below specifications, thus becoming a bottleneck in the development. At the Beijing Materials Technology Institute, Wang Manxia et al. organized the attack on the sealing bottleneck. Together with

the Fourth Shenyang Rubber Plant, the Northwest Rubber Plant, and the Northwest Research Institute for Rubber Products, tens of batches of rubber materials with different properties were used within the short span of several months for trial manufacturing and testing of these different kinds of parts. When the first Chinese-designed rocket was assembled and was delivered from the factory, all eight kinds of rubber components passed quality tests, thus meeting the demands of rocket development.

The chemical engineering system produced liquid oxygen, ethyl alcohol, and other fuels with purity satisfying ground test runs and flight tests, thus ensuring the launch of the first Chinese-made rocket. Shortly afterwards, high-energy fuels generating even higher thrust were developed as propellants in newer rockets.

At about the same time, a number of results were obtained in manufacturing technology; the main results are as follows:

(1) High-temperature soldering: this is a new manufacturing technique for liquid-fueled rocket engine combustion chamber. There were literature sources for the soldering alloys required; whether or not such alloys can be developed within a short time is a key factor as to whether or not the scheme of selecting this new type of combustion chamber for rocket engines can succeed. The following units furnished, on different occasions, raw materials, supplies and smelting equipment, as well as supporting technology: Ministry of Metallurgical Industry, Beijing Iron and Steel College, Shenyang Metals Research Institute, Beijing Electron Tube Plant, Tongren Alloys Plant at Shanghai, and Shanghai iron and Steel Research Institute, among other units. At the Beijing Materials Technology Research Institute, high-paced and repeated experiments and exploration were conducted to finally develop these high-temperature soldering alloys and mastering the vacuum soldering technique. Soon thereafter, under

the leadership of general engineer Gu Guangxu, the Rocket General Assembly Plant, a large high-temperature soldering oven and accessories were built; more than 700 technical experiments were conducted on the soldering materials and soldering simulated workpieces in addition to detonation tests of the simulated workpieces. It was shown that all performance was up to the design and manufacturing requirements, thus filling a technical void of high-temperature soldering and high-temperature soldering alloys in China.

(2) Chemical milling is a special technical method of machining metal parts and components by using the principle of chemical corrosion; the method can be used to machine various types of single- or double-faced parts and components that are difficult or even impossible to machine with conventional machine tools. In the chemical milling technique, metal plate materials are placed in alkaline or acidic solutions for corrosion. A layer of corrosion-proof glue is deposited in advance onto those surfaces not requiring corrosion. This chemical milling is not restricted by material composition and hardness, is unaffected by the thickness of parts, and does not lead to deformation in the machining process, in addition to simplicity of equipment, high productivity, low costs, and no requirement for highly skilled operators. By citing an example of the propellant storage tank, with advances in rocket technology, the storage tank is not only a vessel under internal pressure, but also a component withstanding various external loads of the rocket. In order to meet external loading requirements, the casing should be designed in various lattice structures with reinforcing rib. By adopting chemical milling, the technique of manufacturing this structure will be much simplified, and its scrap weight will be greatly reduced, in addition to higher strength and reduced weight of the casing. If high-strength aluminum alloys are used to build fuel tanks of intermediate-range liquid-fuel rockets, chemical milling can reduce the storage tank weight by 25 to 30%. To implement

the technique of chemical milling, a protective glue with high corrosion stability, long shelf life, and satisfactory stripping ability is required. This kind of protective glue was prepared with success in a joint effort by the Beijing Materials Technology Research Institute and the Tianjin Oils and Paints Plant, thus creating the conditions for using chemical milling technology. Subsequently, different kinds of corrosive liquids were formulated to make use of different materials; chemical milling precision was enhanced by using different measures; and the corrosion rate was accelerated. With unceasing improvements of the chemical milling technology, its range of application will also expand without end, not only in fuel tanks, but also for many kinds of parts and components, not only in aluminum alloys, but also successful development of chemical milling techniques for stainless steel, titanium alloys and other metals. In the eighties, during the development of the fuel tank in the third stage of Changzheng No. 3 rocket, chemical milling was also improved, in achieving the ideal results.

(3) Applications of titanium alloys: these alloys are finding growing use in departments of the aerospace industry because of low specific weight, high strength and satisfactory high-temperature properties. These alloys can be used not only as gas bottles in rockets or satellites, but also applied in many kinds of titanium alloy parts in the satellite reentry compartment structure. By using titanium alloys in the exposed sector of high-attitude engine nozzles, thrust frame, and tightening parts, their structural weight can be greatly reduced. In the early eighties, there were no practical applications of titanium alloys in China. For titanium alloy gas bottles used in rockets, the raw material was provided by the Shenyang Nonferrous Metals Processing Plant; die casting was begun to be used at the Shanghai Heavy Machinery Plant; and later die casting was changed into die forging at the Wuxi Blades Plant. There are two difficult points in titanium alloy machining: one is the complex

forging shapes, and the second is the unsatisfactory welding, easily leading to low-pressure explosions during tests. After repeated tests and steady improvement in technique, these two difficult problems were solved, for higher quality and lower cost. A weight reduction of 60 to 70 kilograms was the result with significant technical and economic benefits. The cost of titanium casting ingots was reduced from 350 yuan per kilogram in 1965 to 60 yuan in 1984, thus opening a good prospect for extensive applications of titanium alloys.

(4) Applications of reinforced plastics: glass fiber-reinforced plastics is one kind of reinforced plastics. This is an important material used in modern aircraft and rockets. With high strength, low density and small thermal conductivity, this reinforced plastic can effectively have the functions of heat insulation and weight reduction in rocket components. In the sixties, China's reinforced-plastics industry was still very young, with inadequate technical resources along with crude equipment. Through a large number of technical experiments by the Materials Technology Research Institute and the No. 251 Plant of the Ministry of Construction Materials, the technique of manufacturing reinforced-plastics was eventually mastered after failures and setbacks, thus filling a technical void for the state.

Responsible for this research task, the No. 251 Plant of the Ministry of Construction Materials was a small factory previously. After the factory personnel accepted the mission of solving bottleneck problems of reinforced-plastics, the factory grew in size with this development. In the eighties, this plant not only could provide reinforced-plastics used in rockets, but also reinforced-concrete for oxygen gas bottles, moisture-proof cylinders, seed compartment casings of tractors, locomotive rolling stock, pressure boats and household appliances. This plant has become a well-known research and production unit, on a

relatively large scale, for glass fiber-reinforced plastics in China, making important contributions to China's aerospace activities.

(5) Spraying and coating technology: high-melting point oxides (such as alumina) are melted at high temperatures and the molten droplets spread evenly onto the surface of metal or nonmetal parts, thus protecting the parts and components against damage from high temperatures. In the early sixties, crude equipment was used to conduct experiments by the Beijing Materials Technology Research Institute, thus yielding good results. Later, the advanced plasma spraying and coating equipment was used. When using this technology in the machine-building industry, appreciable results were also obtained. For instance, an item of equipment was imported from abroad by a factory; the service life of its piston was less than a year. After the plasma spray and coating method was used to restore the part, the useful service life was greatly extended. With protective measures using oil-based paints and zinc dipping for high tension iron towers for power transmission, generally the effective life is three years; however, generally plastic spraying and coating can extend the service life to several decades.

In the mid-sixties, with growing development of China's intermediate, long-range, and intercontinental rockets, even higher requirements were imposed on materials and technology.

First, high-strength standard steel, high-temperature alloys used in turbine blades, and aluminum-copper alloys used in making fuel tanks were developed and provisionally made for rocket engines by metallurgical industry units; thus the structural level of China's rockets attained a new high, shortening the gap of technical levels in similar products made abroad. At the very beginning, aluminum-magnesium alloys were used for fuel tanks of

liquid-fueled rockets in China; however, such an alloy does not have adequate strength. Therefore, aluminum-copper alloys were developed in order to satisfy demands of large carrier rockets. After strengthening with heat treatment, the yield strength of such alloys is higher by 100% over the aluminum-magnesium alloys, but with the shortcoming of inadequate weldability. In Beijing, Shanghai, and elsewhere, special welding rods and technical measures were developed, thus solving the problem of brittle cracking of weld seams. Later, some other problems appeared involving cracks in the welded workpieces of these alloys under special conditions during storage; in addition, ways were explored in practical situations to avoid the cracking of these products. Later, in joint efforts by the Northeast Light Alloys Processing Plant and the Beijing Materials Technology Research Institute, another kind of high strength aluminum alloy was successfully developed. At high and low temperatures, this alloy has better mechanical properties in addition to the unique advantage of weldability. All these results meant that the application of high-strength aluminum alloys was brought to a new level.

In combining with China's unique resources, and demands in the metallurgical industry, the following kinds of new materials were developed: various kinds of new metal materials, several kinds of low-alloy, super-high-strength steel, and tungsten-infiltrating copper materials. In the case of nonmetal materials, more stringent requirements were imposed on heat-resistant materials deriving from rocket technology. With coordination between the Beijing Materials Technology Research Institute and related units in China, bottleneck problems were attacked in an organized effort, and carbon-carbon composite materials were developed. After mechanical and physical determinations, along with burn corrosion and simulation experiments, it was revealed that these composite materials have much superior properties than fiberglass-reinforced materials,

for use as heat- and grinding-resistant materials. In addition, experiments and research were also pursued on die casting-oriented high-silica-phenolformaldehyde, and graphite materials, as well as carbon-quartz materials.

With the adoption of new high-energy propellants for rocket engines, new requirements were also imposed on seals. New high-energy propellants have high corrosion and dissolving function with respect to seal materials. At the Beijing Chemical Engineering Research Academy and the Beijing materials Technology Research Institute, a new rubber material was used to press and make various kinds of seals; this practice was successfully applied on various dynamic and static seal systems in rockets with storage life of 10 years or more. In the mid-sixties, fluoroplastic seals were successfully developed at the Changchun Applied Chemistry Research Institute, the Shanghai organic Chemistry Research Institute, and the Shanghai Plastic Research Institute. This kind of seals has outstanding thermoplasticity; its successful development meant a further step of improvements in seals functioning in the presence of oxidizers. In the seventies, another kind of fluororubber products was developed at the Chenguang Chemical Engineering Research Academy; after hundreds of batches in compounding and technical experiments, the technical void of sealing materials with resistance to powerful oxidizers was filled, thus satisfying the use requirements of long-range rockets.

In processing technology, precision casting techniques were applied. In these techniques, there are many advantages compared with metal-cutting techniques, capable of producing very complexly shaped parts and greatly reducing loss of raw materials during machining. At the Beijing Materials Technology Research Institute, precision casting methods were used to cast parts such as small nozzles, turbine rotors, and turbine casings. Very

satisfactory results were also obtained in machining and application of beryllium alloys.

Since the layout of low-temperature propellants was adopted in the Changzheng No. 3 rocket, many newer subjects and requirements were imposed on materials technology, mainly as follows.

(1) Trial production of cryogenic-oriented stainless steel: in order to satisfy low-temperature use requirements, new cryogenic-oriented stainless steels were successfully developed in a joint effort of the Beijing Iron and Steel General Research Academy, Fushun Steel Mill, and the Beijing Materials Technology Research Institute. This steel has outstanding low-temperature properties and satisfactory room-temperature properties, in addition to exhibiting mirror-like properties in satisfying requirements of high-temperature soldering techniques for materials in the outer wall of the combustion chamber in a hydrogen-oxygen engine, with very good results. In a large number of ground and flight tests of short and long-range rockets, quality problems never occurred. The successful development of new cryogenic stainless steel marked an occasion of gradual maturing of research and application of China's metal materials.

(2) Adoption of perforated sweating materials: in the presence of a high-temperature burning gas inside a combustion chamber, the heating surface temperature of the injector face panel in the third-stage engine of the Changzheng No. 3 rocket, the temperature at the heated surface is upwards of 3000° C; thus, the liquid hydrogen on the other side of the partition will rapidly gasify, thus the cooling effect will be appreciably lowered, and hence very great thermal stresses will be generated in the face panel, thus causing warping and unstable combustion, even extending to severe corrosion of the face panel. In a joint

effort by the Beijing Iron and Steel Research Academy, the Taiyuan Steel Mill, the Tianjin Metallurgical Materials Research Institute, Metal Products Plant, Shanghai Nonferrous Metal Research Institute, and Beijing Materials Technology Research Institute, effective technical methods were adopted to impart a degree of hydrogen permeability to the face panel. After numerous experiments, various property parameters of the face panel were determined. Thus, a major difficult problem was solved for hydrogen-oxygen engines because the phenomena of burn damage and deformation never occurred in test runs.

(3) The honeycomb heat-insulated common bottom of fuel tanks: the adoption of honeycomb common-bottom structure of two fuels tanks, containing hydrogen and oxygen, is another key problem of the third stage of the Changzheng No. 3 rocket. Adoption of this structure can shorten the fuel tank length by 1.4 m and lighten fuel tank by 200 kg. In this structure, face plates cover both surfaces of metal or nonmetal honeycomb-sandwich core, in addition to cementing, thermal pressure, and solidification. This technique has the advantages of light weight and high rigidity. To solve the cementing problem, a structural cement with high strength and high toughness, in addition to low temperature resistance, was developed at the Beijing Materials Technology Research Institute. The strength performance of this structural cement at low and room temperatures exceeds that of various low-temperature cements available in China, thus providing the material conditions for machining the honeycomb heat-insulated common bottom. Machining precision of the honeycomb sandwich-core shaped surface is central to ensuring cementing quality. To achieve compression and cementing between the upper and lower canopies and the honeycomb sandwich core, a set of contour following machine equipment was designed and built at the Beijing Research and Design Institute of Machinery and Electrical Equipment, as well as the Rocket General Assembly Plant; after numerous experiments

a multiple thin-film cementing and sealing technique was used to sharply raise the quality of cementing the common-bottom and canopy, thus meeting the requirements of large-area sealing.

(4) Low-temperature heat-insulated materials: liquid hydrogen readily evaporates when heated to room temperature; its volume will expand 800 times. Thus, not only is there great loss of liquid hydrogen, but also this may lead to explosion of the tank casing if not released in time. Heat insulation of a fuel tank is a key technique. After repeated experiments and studies, a heat-insulating measure of multilayer structure was adopted. Various layers of the material have their respective function, forming a very compatible entity, and exerting very high heat-insulation. Materials such as the following are available: low-temperature cement, fiberglass fabric, polyaminoester, aluminum-coated thin film, and heat-reflecting paint. Multilayer heat-insulating materials should also be adopted for liquid hydrogen transfer pipes in order to satisfy design and operational requirements.

(5) Rectifying cover of honeycomb sandwich structure: in the structure of the rectifying cover, there are terminal, dual cone section, straight-cylinder section, and inverted cone, made of, respectively, fiberglass-reinforced plastics, its honeycomb structure, aluminum honeycomb structure, and aluminum alloy chemically milled wall plate. This series of complex work stages relied on experiments and exploration to enable the products to attain bearing capacity values as required in design, in addition to passing vibration experiments, rapid external pressure reduction experiments, and cover separation experiments. The honeycomb sandwich structure can bring about a 20-30% weight reduction over the truss covering scheme riveting structure. The rectifying cover of this structure was used in an experimental communication satellite launched in April 1984; this structure was a success.

(6) Trumpet antenna made of carbon fiber composite material: a trumpet antenna is an important component for liaison between an communication satellite and the ground station. When a satellite operates in a high-vacuum orbit, its antenna is subjected to rapid temperature changes. To ensure high gain and orientation of the antenna, the lower its weight the better, and the smaller the material deformation the better, in order to ensure orientation precision. Otherwise, a slight deviation will lead to thousands of miles of straying, thus affecting the reception and the transmission effects of the satellite's communication signals. Therefore, the trumpet antenna used in China's experimental communication satellite employs carbon fiber composite material. Through repeated experiments, the properties of this trumpet structure in a high vacuum can be reduced by 45% in weight compared to aluminum alloy antennas. In order to align the aperture of the trumpet in the antenna with the ground surface and to eliminate the effect on the antenna due to satellite spinning, carbon fiber composite tube materials are used for the spin-cancellation support frame, thus ensuring strength, rigidity and weight reduction.

(7) Engineering plastic supporting frame with high performance: reinforced nylon is used as the supporting frame material in the communication satellite carrier rocket. This supporting frame is formed by extrusion; this technique is simple and low in cost, as well as being light in weight. This was the first time that engineering plastics were used as components for secondary bearing members in a rocket.

There are many other new materials, such as catalysts for anhydrous hydrazine as fuel for attitude control rocket engines, tungsten balls for surface hardening treatment of the nutation damper, as well as organic and inorganic temperature control paints, among other materials.

In addition to these materials used in components mentioned above, high-strength rotational compression technique, high-temperature thermal expansion technique, superplasticity forming technique, and electric casting technique are used in the forming technology for making the systems of a carrier rocket. In welding technology, new methods of electron beam welding, plasma welding, laser welding, and diffusion welding are also applied, in addition to extensive applications of argon arc welding, contact welding and soldering. China's labor hero, Chen Zhongsheng, at the Capital Machinery Plant, mastered a high new technique of cast iron cold welding after many years' study and practice; the new technique was publicized. In surface treatment, plasma injection and coating, metallization of nonmetal materials, iron coating, vacuum deposition, and vacuum sputtering film deposition were developed in addition to the traditional surface treatment methods. These techniques were publicized and applied in production on a provisional basis. These new techniques can also be publicized and applied in other industries for higher economic benefit.

Section 2. Large Experimental Facilities

With advances in aerospace activities, China's aerospace experimental techniques were also greatly developed and improved on, thus gradually forming an independent and integral experimental system from components to the entire rocket as well as the serialization of rockets and satellites. These achievements play an increasingly greater role in aerospace activities. A rocket and a satellite are complex structures constituting tens of thousands, or even hundreds of thousands of parts and components. In addition to complex factors of conditions in materials, technology, and operation, it is impossible to obtain high performance and high reliability final products even by highly sophisticated engineers with their

exhaustive designs and precision theoretical computations, apart from numerous experiments at various stages and complex environments. Therefore, the ground experimental facilities and equipment have an important standing in aerospace engineering; the development of models is an indispensable material foundation. The difficulties and complexities in building certain facilities and development of equipment are even not lower than the development of a new model.

The entire experiments are multilayered in the form of a pyramid; from single-item preliminary research and experiments to the component experiments of systems, subsystem experiments, whole-system ground experiments, to the flight experiments, the number of experiments range from high to low, and the experimental range is from small to large, as well as from local to the entire object. Based on development requirements, there are regular experiments, routine experiments, dynamic experiments, static experiments, and environmental experiments, for the ground category; matching experiments, analog simulated experiments, whole-system experiments, and service life experiments, for the transportation category.

Experimentation quality depends on improvements in experimental equipment and technique, as well as advances in measuring techniques. Steady improvements in measuring techniques and steady upgrading of precision in measurements and testing also promote steady development of experimental techniques.

In a sense, the development process of the entire rocket and the satellite is a process of ground experiments and flight experiments. The ground experiments are the precursors of flight experiments; however, flight experiments are the continuation of ground experiments. The latter are an important means of inspecting the quality of design and manufacturing. Sufficient

experiments on the environments possibly encountered in simulated flights can expose and solve problems before flight experiments; this is a very important measure for ensuring success in flight experiments. For an intermediate short-range rocket designed in China in 1962, the rocket fell and was destroyed in the vicinity of the launch pad immediately after launch. One lesson to be drawn was that the ground experiments were improperly done. Later, 17 major experiments were repeated, such as strength experiments, environmental experiments, transportation experiments, vibration experiments, comprehensive matching simulation experiments, engine test firings, and test firings of the entire rocket. This deficiency was remedied. A number of urgently needed large ground experimental facilities were built in rapid succession.

At that time, it was quite difficult to build these large experimental equipment and facilities urgently required for development. These items were brand-new in China, without any precedents and without prototypes. It depended entirely on trial and error; even some slight information obtained was in bits and pieces, far from complete. Practical problems confronted by research personnel in practice only can be solved through experiments. Thus, different requirements were imposed on experimental facilities. Based on these requirements, two research contingents were organized: one contingent engaged in designing the manufacturing process; and the other contingent engaged in the design of civil construction. Inspection with application by experiments was completed on the completed experimental facilities. Defects were unceasingly remedied. Eventually a set of relatively complete ground experimental system was formed. Under present standards, some experimental facilities and equipment were old and obsolete. However, these facilities had their merits in China's developmental history of aerospace activities. Citing an example of a liquid-fuel rocket engine, several test run stands built in the sixties were

relatively simple and crude in inspection and measuring techniques. There were few measuring parameters with low precision. Generally, data displays were obtained from the simulated electronic oscillographs and pressure gauges. After photographing and manual interpretation, test run reports were provided. The measuring techniques were developed from the multichannel parallel analogue type records in the sixties to the digital type record displays in the seventies. In the eighties, automatic monitoring and control systems centering on electronic computers were used; in addition, a series of measuring technique of low temperature and high vacuum was applied in a technical breakthrough; thus, the measuring technique entered a new level.

Although China's current experimental facilities and equipment are still relatively backward compared with those of advanced countries, yet these relatively backward equipment and facilities were used by China to develop aerospace products with advanced technical levels. With progress of the Four Modernizations, China's large experimental equipment will develop toward modernization and automation.

The major large experimental equipment and facilities can be described:

(A) Wind tunnel facilities

In the late fifties and early sixties, the Number 1 Academy of the Defense Ministry began preparing for the construction of an aerodynamic research base centering on a group of wind tunnels. In 1959, subsonic wind tunnels were accepted for operation. In 1962, transonic and supersonic wind tunnels were accepted for operation. There was successive construction of hypersonic wind tunnels, low speed wind tunnels, electric arc wind tunnels, electric arc heaters, subsonic electric arc heaters, hypersonic low density wind tunnels, and hypersonic

artillery wind tunnels. The Beijing Aerodynamic Research Institute was responsible for wind tunnel experiments of multiple models of rockets and satellites. These experimental data can be used to check whether the calculation methods and theoretical analysis are correct. In aerodynamic research on carrier rockets, the following categories of problems were worked on with experimental results: wind-generated stimulated vibrations, flow at the bottom of a four-strap-on rocket engine, separation between stages, separation between satellite and rocket, hinge moment, drum-shaped package analysis, pneumatic heating, and liquid sloshing. The successful solutions of these problems created conditions for developing models.

(B) Environmental experimental facilities (including dynamic, static, vibrational, and vacuum experimental facilities)

(1) Static experimental hall

Static experiments are an important means to check whether or not the structural strength of products can satisfy design requirements, and to check whether or not the structural calculation method is correct.

The static experimental hall is a project with high engineering volume and complex technology. Only a subproject of bearing piles, it lasted more than eight months in driving more than 1300 piles with the longest pile being more than 10 m. In the hall there are load-bearing walls, load-bearing excavations, and floors of more than 6000 m^2. During construction, it required two pourings of more than 5000 m^3 of concrete without any pouring seams visible; the levelness was not to be more than 5 mm (actually, 1 mm was the result). This was still the first time in China that concrete construction for an area this large and with this level of precision had been achieved. With the participation of experts from the Ministries of Metallurgy and

Hydroelectric Power, as well as other units, several discussions and certifications were conducted. More than 200 workers were organized in October 1963. In a continuous operation of 36 hours, the mission was brought to a successful conclusion as per plan.

The entire hall can be used to conduct scientific research and experiments of structural strength and stability, including the static loading axial-direction compression, external and internal pressures, bending and combination load experiments on structures of the entire rocket and sectors; as well as vibration experiments of the entire rocket and the other related special-topic experiments.

The static experimental hall was completed in 1963. Successively, nearly one thousand static experiments were conducted. With advances in experimental technology, and applications of digital minicomputers, at present the automation of static experiments has been basically accomplished.

(2) Large vertical type dynamic equilibrium machine

In a high-speed spinning satellite, it is required that its mass strictly symmetrically rotates around its axis; otherwise, noise or swinging will occur during spinning. Similarly, a spinning satellite also requires symmetric mass distribution around the spinning axis; otherwise, large nutation angles will be induced during spinning. This phenomenon caused great damages to the communication satellite, not only leading to deviations of velocity direction when the apogee rocket engine in the satellite operated, but also resulted in delayed orientation toward the earth by the wave beam of the orientation antenna. Hence, after general assembly, measurements and testing of a communication satellite, experiments should be conducted on a

dynamic equilibrium machine, for highly precise compensation of dynamic equilibrium.

A dynamic equilibrium machine requires high precision and low rotating speed by using gas-lubricated bearings. The mechanical components support the satellite and are sensitive to nonequilibrium of satellite motion. The electrical components can convert the dynamic nonequilibrium quantities into electrical quantities for measurement. The key mechanical component is the knife-edge component for supporting the satellite. For the knife-edge component, there should be high hardness and high machining precision of the knife edge. In 1976, after the Satellite General Assembly Plant accepted the task of trial manufacture, the satellite passed its certification five years later. After the equipment was in operation, it passed all measurement and experimental tests with high marks in spinning tests, dynamic and static equilibrium, and as well as longitudinal direction inertial torque of the communication satellite.

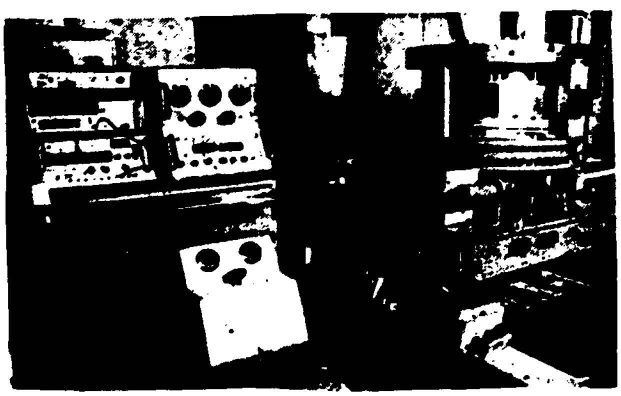

Fig. 117. Large vertical type dynamic machine

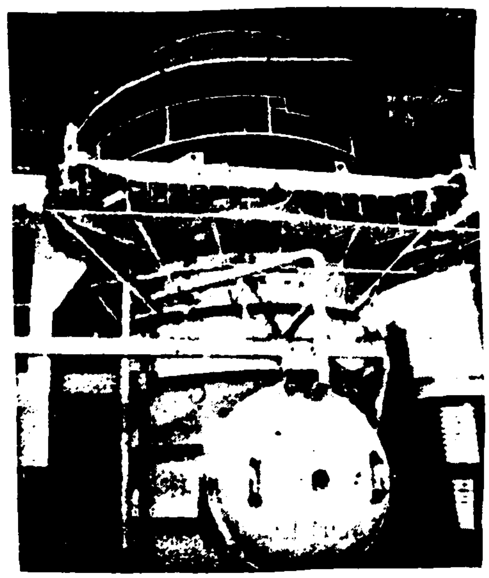

Fig. 118. KM_4 thermovacuum experimental equipmen

(3) Large thermovacuum experimental equipment

In space flight, a satellite is in a vacuum environment with alternating high and low temperatures. In the geostationary orbit, the degree of vacuum is 10^{-13} torr. The satellite temperature varies with the status of solar illumination. When the sun is blocked by the earth so that its rays cannot reach the satellite, its temperature drops very rapidly. When the sun illuminates the satellite, its temperature becomes very high. Such rapid change in temperature directly affects instrumental performance. To ensure successful flights, thermovacuum experiments should be conducted on the ground in order to simulate actual flight conditions of the satellite.

At the Beijing Research Institute of Environmental Experimental Engineering and at the Shanghai Research Institute of Satellite Engineering, different-sized thermovacuum simulation rooms were built with diameters of 1, 2, 3, 5, and 7 meters. In these simulation rooms, the degree of vacuum can be as high as 10^{-7} torr. To simulate heating of the satellite by the sun and earth, far-infrared heaters were installed in the rooms; some rooms are equipped with xenon lamp solar simulators.

The KM_4 vacuum simulation room is currently China's largest thermovacuum equipment; this is a vertical type vacuum simulation equipment with a 7 m diameter and 12 m in height; in addition, there are the preceding stage machinery pump and four oil diffusion pumps with suction rate of 5000 liters/s and a refrigeration capacity of 1200 W, along a helium deep cooling pump with suction rate of 1.5×10^6 liters/s with a refrigeration capacity of 1200 W. Under no-load conditions, the degree of vacuum in the room can reach 10^{-6} torr for 10 h of pump operation. For 24 h of pump operation, the degree of vacuum may reach 4×10^{-8} torr. There is also an attitude simulation with

double-axle rotation in the vacuum room in order to simulate the direction of motion of a satellite relative to solar heating. These items of equipment were developed by the Beijing Research Institute of Environmental Experimental Engineering and the Lanzhou Physics Institute (among other units) after a decade's effort. These items of equipment operated since 1976.

The reentry type satellite and experimental communication satellite were, respectively, subjected to thermovacuum experiments of the entire satellite in KM_3 and KM_4 simulation rooms.

(4) Vibration experimental tower for entire rocket

At launch and during the flight of a large rocket, there are various kinds of dynamic interference due to ignition, separation, thrust vibration, noise, and gasdynamics in the internal or external environments; possibly, two kinds of vibration problems may exist: one is the problem of vibration stability and the other is the problem of vibration response. Vibration experiments with the entire rocket can serve in determining natural vibrational frequency and vibration types of the rocket, and also in studying response problems. Results in the former are helpful to the longitudinal direction coupling vibration analysis in designing control systems, thus avoiding instability phenomena during flight. In the latter case, the local natural vibration environment can be determined in order to take the appropriate countermeasures.

To ensure flight reliability of large rockets, it is far from adequate to rely solely on theoretical calculations during preliminary design and many hypothetical and simplified mathematical models; the entire-rocket vibration experiments should be conducted in the vibration tower. Through experiments, effective countermeasures can be adopted for various vibrational

problems thus exposed in order to solve the problems of stability and dynamic strength.

The entire-rocket vibration tower was built relying completely on China's technical resources. The entire engineering project only spent a little over a year, completed in early 1964. The main structure of the experimental tower is about 50 m high; the rocket is suspended in the center, and 13 floors were built along sides of it, with operational rooms, storage rooms, elevators, and hoists in the top floor. There are tunnels in the ground floor, in which bearing rails were laid. Around the rocket there are 11 floors of receiving, exiting and stationary operational platforms with a diameter of 4 m. Closed-circuit television was installed in every floor to monitor the rocket body.

The entire-rocket vibration tower can be used to determine precisely the inherent vibrational properties of a carrier rocket, thus realistically simulating rocket vibration in space. The vibration tower has become an indispensable item of equipment in the rocket model developmental process,.

In April 1964, China's first entire-rocket vibration experiment was conducted in the tower; the rocket was the intermediate short-range rocket designed in China; the experiments ensured the successful test flight. Successively, vibration experiments were conducted on various types of carrier rockets.

The vibration experiments on the entire rocket and the satellite-bound components were conducted on 5- and 17-ton electromagnetic vibration platforms and a 20-ton hydraulic vibration platform. Complete sets of data were obtained for technical experiment satellites and experimental communication satellites after experimentation with these items of equipment.

(5) Large centrifuge

Designed by the Beijing Research Institute of Environmental Experimental Engineering, the large centrifuge has an effective rotary radius of 10 to 12 m; 12-m, three-shaft compartments were installed with maximum load of 5 m, maximum acceleration of 25 g, and 42 kW of driving power; the centrifuge is computer-controlled. The centrifuge was used to conduct experiments on centrifugal acceleration of satellite and spacecraft, and can also be used in training astronauts. This is currently China's most advanced large centrifuge with the highest degree of automation, either for use in automatic or manual operation that has the advantage of multiple uses in a single machine.

1 2

Fig. 119. (1 and 2) Large centrifuges

Developed by the Shanghai Research Institute of Satellite Engineering, the large centrifuge has a platform surface of 3 x 2 x 2 cubic meters, with 2 tons maximum loading, 5.2 to 7.7 m of effective rotary radius, 15 m of arm length, 17 to 18 rpm as the range of revolution speed, and 2 to 17 g for the maximum centrifugal overloading. Centrifugal overloading environmental

simulation experiments of technical experimental satellites (developed in Shanghai) were conducted on this item of equipment; in addition, gyroscope component performance experiments and single machine overloading equipment (used for Fengbao No. 1 rocket) were conducted on this item of equipment.

(6) Large drop type impact experimental platform

This is a large impact experimental platform, measuring 2.6 x 2.6 x 3 cubic meters; the effective rising elevation is 15 m; the platform loading is 2 tons; and the peak value acceleration of the response wave form is 50 g. The experimental platform was used to conduct impact experiments for the instrument compartments in technical experimental satellites, meteorological satellites, and reentry type remote-sensing satellites. In addition, experiments were conducted on single machines in long-range rockets and experimental communication satellites. In addition, there were elevator drop simulation experiments conducted for civilian departments.

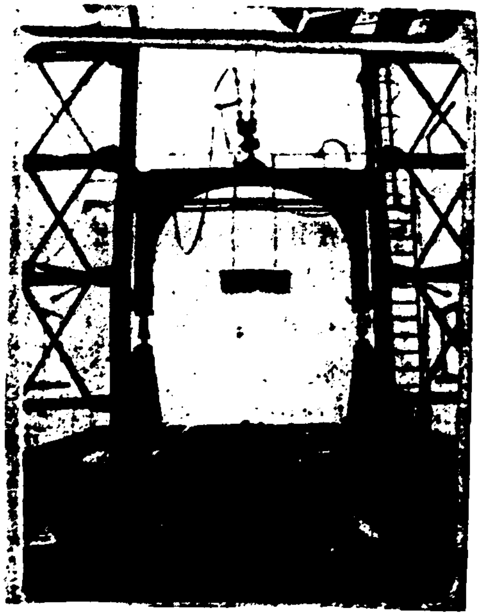

Fig. 120. Drop type impact experimental platform

(7) Large high-precision rotary platform

This is a ground equipment item developed by the Dongfang Scientific Instrument Plant in Beijing for installation and precision inspection of sensing components and final controlling element in satellite attitude control systems. The diameter of the platform surface of the rotary platform is 1200 mm. At a loading of 1500 kg, no heavy sensations during cranking were felt. The nonlevelness (concavity) of the platform surface is less than 0.02 mm; the jerkiness of the terminal surface or along the diametral direction is less than 0.01 mm. For precision in angular measurement, the reading precision is 1 angular second, and the positioning precision is 6 angular seconds. Applying the combination (machinery and electrical equipment) operational mode, the high-precision angular rotation of the platform is accomplished by mechanical transmission; the angular measurements are displayed with induction synthesizers and digital meters. The rotary precision is high and bearing capacity are high, along with steady and flexible rotation, precise and convenient positioning, and simplicity of operation. A tiny torque motor can drive rotary platform, consuming only 12 W of power.

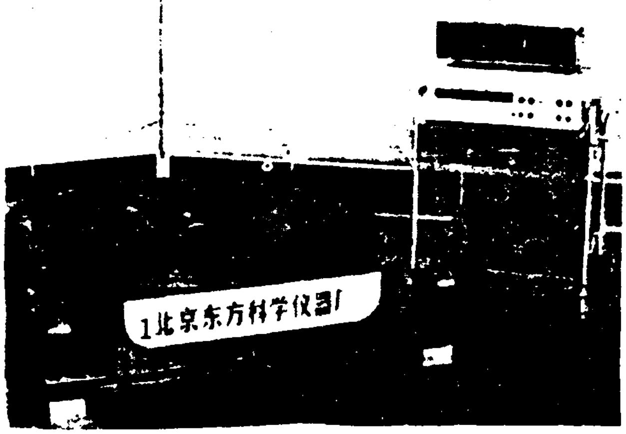

Fig. 121. Large high-precision rotary platform
KEY: 1. Dongfang Scientific Instruments Plant in Beijing

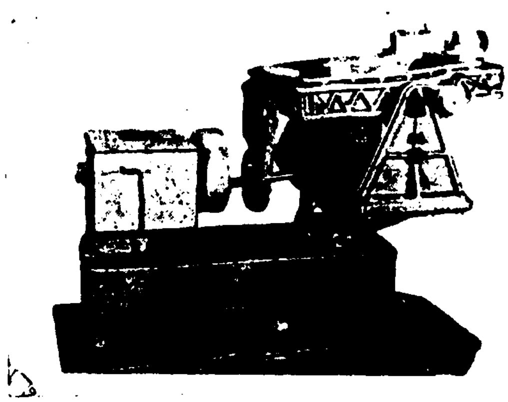

Fig. 122. Three-shaft swing platform

The large high-precision rotary platform began to be developed in 1977. In 1980 and 1981, three such platforms were assembled and adjusted, successively, thus filling a technical void in China in large precision rotary platforms larger than 800 mm. These platforms led in technology then in China and were comparable to rotary platforms abroad in the same class.

Besides, three-shaft swing platforms for measurement and testing of the dynamic precision of gyroscopic platforms, and precision inclined rotary platforms used for static precision measurement and testing of gyroscope platforms were developed, respectively, by the Inertial Equipment Research Institute, Carrier Rocket General Assembly Plant, and the Second Beijing Machine Tool Plant.

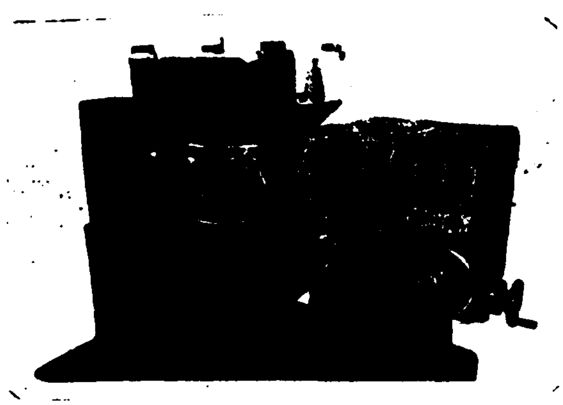

Fig. 123. Precision inclination rotary platform

(C) Engine Test Facilities

In the rocket engine development process, a series of experiments dealing with components to single machines, as well as to all the systems in order to acquire necessary data to certify design correctness.

(1) Components experimental room

Numerous experimental studies have to be conducted on components in the preliminary research stage, model stage, and preliminary model stage of new model rocket engines in order to clarify the existing problems as well as to explore ways and rational means of solving these problems. For example, atomizing and flow experiments should be conducted on nozzles of thrust chambers as well as the nose cone; cooling and liquid flow experiments of thrust compartments; performance experiments of pumps and automatic devices; unified experiments of combustion gas generators as well as heat exchangers and turbopumps; medium experiments of bearings, and compatibility experiments of materials, among others. Therefore, experimental chambers of appropriate scales should be built, such as hydraulic experimental rooms, medium experimental rooms, as well as thermal experimental rooms of turbopump linkage moving apparatus. By citing an example of a hydraulic experimental room, this is one of a series of component experiments on a rocket engine. It is more than economically feasible and not safe if a propellant is used in medium experiments. Therefore, many experiments use water as the medium before theoretical conversion to experimental results for a real medium (propellant).

No. 1 pump complex is the largest pump complex in the hydraulic experimental room; the pump complex consists of a main power room, an experimental partition, measuring and control components, and a 100 m^3 capacity outdoor water pond. The pump complex is driven by a 2500 kW dual armature direct current motor with double step-up rpm increase. The direct current power is supplied by a 3000 kW direct current generator driven by a synchronous alternating-current motor of 10,000 V and 3450 kW in power. The pump complex was built in early 1957 and began operation in 1961. Up to now, hydraulic experiments were conducted on thousands of rocket engines. Thereafter, the hydraulic experimentation rooms built in liquid-fuel rocket

engine third-line base areas not only have experimental parameters developed to a high power, and high precision, but also achieving high precision, high reliability, and data collection automation in measuring and test technology, thus shortening the time of data processing.

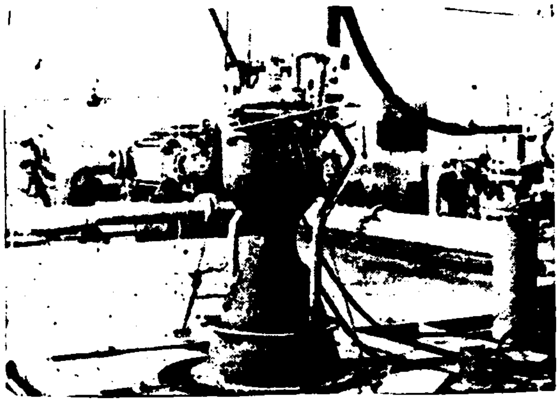

Fig. 124. Liquid flow experiments of rocket engine

(2) Test run stand of rocket engine

The dual-test position and the multiple-usage large rocket engine test stand is one of four test run stands organized to be built by expert Wang Ziren; the test run stand was completed in November 1964. Open-access systems are installed in the dual-test positions, which have independent oxidizer systems and fuel systems, capable of simultaneously conducting experimental preparations for two different models of rocket engines by using different oxidizers and fuels. The entire test run stand is compact in structure and a rational layout; not only can it proceed with test runs of single rocket engines, or test runs of four rocket engines in parallel, but it can also serve in conducting simulated high altitude (18 km) test runs for 30-ton thrust rocket engines. For many years, single-rocket engine ground tests of multiple models were run numerous times, as well

as simulated high altitude of the Changzheng No. 2 second-stage rocket engine.

Fig. 125. Dual-test run positions and multiple-use test run stand for rocket engines

The large-thrust class large-rocket engine test stand was built and operated in 1969; this is China's largest test run stand for liquid-fuel rocket engines. The main structure of the test stand is 59 m high and 41 meters long, as well as 22 m for the largest width, and construction floor space of 39,600 m^2.

The main features of this test run stand are gigantic-sized equipment, high precision, large test runs capable of withstanding large thrusts, eight propellant tanks of 65 m^3 each, 575 valves of different kinds and different diameters, water-cooling type flame deflector groove with 35,370 water nozzles of 7.9 tons/s water flow rate, and a high elevation water pond of 3000 tons capacity.

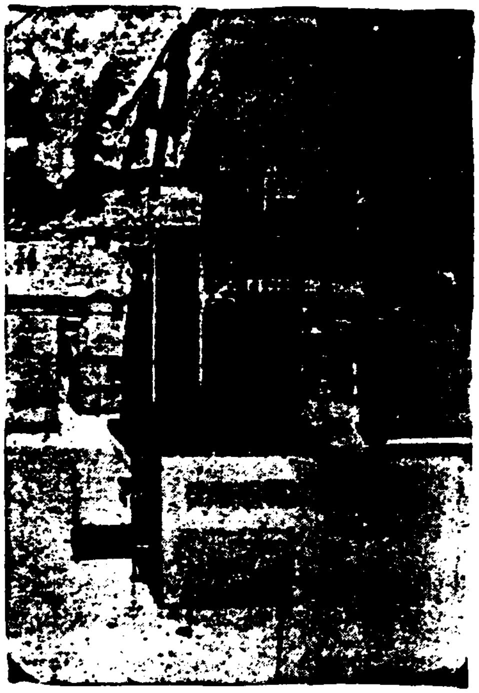

Fig. 126. large rocket engine test run stand

This project was designed and built as organized by experts Xu Jian and Xu Qing'an and other technicians; the ground experiments of China's long-range rockets and the Changzheng No. 2 rocket were conducted here.

In the early seventies, moreover, China built another large-thrust class large-test run stand; some test runs of Fengbao No. 1 and Changzheng No. 3 rocket engines were conducted there.

In the Changzheng No. 3 carrier rocket development, a test run stand for hydrogen-oxygen rocket engines and a simulated high-altitude test run stand were built. These two test run stands provided important conditions for the development of Changzheng No. 3.

(D) Tethered test run stand for entire rocket

The entire rocket tethered test run is also called the ground test of the whole system; this is a large test in the later period of rocket development. After passing a series of experiments on the rocket subsystems, reliability of the entire rocket system should be examined. In the entire-rocket test run, all components of the subsystems are assembled for conducting tests based on flight procedures to examine reliability and coordination of these systems in order to expose some unforeseen problems as a final preparation for flight tests. Therefore, the all-system test run is a crucial stage in rocket development.

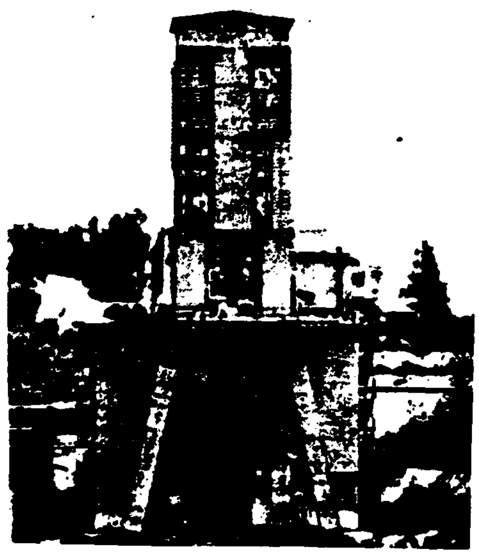

Fig. 127. Test run stand of hydrogen-oxygen rocket engine

The entire-rocket tethered run stand was also designed with China's own technical resources. The test run stand consists of 22 systems, including propellant system, gas source and power distribution system, control system, horizontal and vertical measurement and test system, wired measurement system, and telemetry system. The main structure construction consists of a

30 m high iron tower for installing and testing rockets, a 17.5 m deep rocket turning pit, a 30 ton cantilever hoist, a 33 m deep flame deflector trough, and a 23 m deep underground five-story structure poured with reinforced concrete. At the front of the main structure, there are two 33 m high reinforced concrete columns with a 2 x 2 m^2 cross-section; the columns resemble two legs of a giant erecting on a hilltop (such a magnificent view). After completion of the test run stand, dozens of entire-rocket tethered test runs and hundreds of large supplementary tests were conducted one after the other.

(E) Simulated analog facilities

These simulated analog experiments are important means and indispensable design procedures of attitude control systems of rockets and satellites. The simulated experiments have the following purposes: first of all, to check whether the theoretical analysis of the attitude control system is correct; to check the effects on system integrity of various factors under working conditions in order to supplement the theoretical analysis, thus providing an experimental basis of determining the system parameters and to check the network parameters. In addition, the simulated facilities can expose malfunctions in flight tests in order to provide a basis for design improvements.

The basic principle followed in simulation technology is the theorem of similarity--these are geometric similarity, performance similarity, and environmental similarity. The fundamental methods are mathematical simulation, semi-object simulation (semi-physical simulation), and object simulation (physical simulation). Over the span of more than two decades, dozens of object simulation experiments were conducted at this set of control system simulated analog equipment and ground simulated rotary stand; sloshing stability of Changzheng No. 1 was improved; the networking parameters were adjusted and their

reliability enhanced with such object simulated experiments, thus making a contribution to successful launching of China's first artificial earth satellite. Later, multiple simulated experiments were conducted for Changzheng No. 3 rocket, thus studying the effect on the system of third-level sliding, sloshing, damping, and to interference on assembly stability by longitudinal direction coupling vibration. Thus, correctness of the system was verified and appropriate measures were taken.

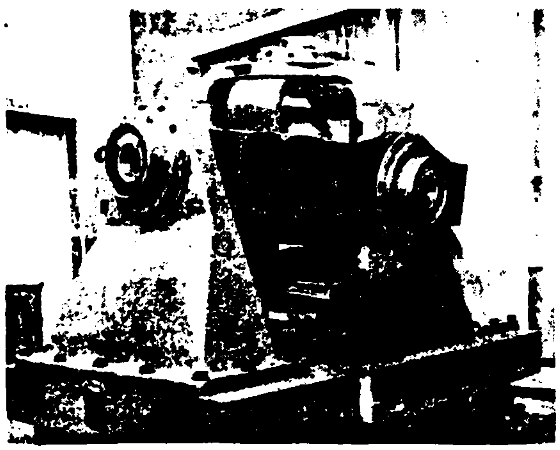

Fig. 128. Ground simulated rotary stand

Fig. 129. Simulated analog equipment

(F) Antenna experimentation facilities

An antenna serves as the ears and eyes of a radio system. Rocket and satellite antennas constitute a new branch of radio engineering, related to extensive aspects with profound theories. It is required that the experimental equipment be complex and precise. In the early sixties, China's first large wooden structure antenna experimental hall was built with 26 m spans; this is a bowl-shaped truss structure of glued wood, without any

metals. After numerous system experiments, high quality red pine was selected for precise machining. The direction in which the force acts is selected to parallel the wood texture in gluing. Eventually, an experimental hall without any iron nails was completed.

In the seventies, a microwave darkroom and ground antenna experimental proving ground were designed in China, in which the appropriate equipment and instruments were installed.

These facilities smoothly accomplished dozens of experimental missions of antennas in various models. In addition, data of remote metering, external measurement, safety, and control were obtained, thus making a contribution to the experimentation.

(G) Equipment to check leakage

In order to ensure long-term steady operations of satellite control systems under conditions of 20 atmospheric pressures, requirements on gas hermeticity are very high. Even in high-pressure operational situations, the leakage rate per second of the entire satellite should not exceed 4.56×10^{-4} standard mm. In other words, this standard index is exceeded if a tiny leakage of microparticles 50 micrometers in diameter (corresponding to one-half of a human hair diameter) leaked between two adjacent threads. This microleakage can lead to variations of satellite spinning speed, orbit, or attitude; to prevent such microleakage, the attitude control rocket engine will exhaust its fuel too early so that satellite service life cannot be maintained.

For a long-lived communication satellite, the method of gas filling pressure constancy cannot be used in checking leakage. With support by Fudan University in Shanghai, the Beijing Metal Structure Plant, and the No. 263 Xi'an Plant, the Satellite General Assembly Plant developed a highly sensitive leakage

detection unit using an isotope krypton-85 was developed, after little more than three years. The equipment was tested successfully on the first time.

Fig. 130. Krypton-85 high-sensitivity leakage detector

For leakage detection of a liquid hydrogen tank in a rocket, a helium mass spectrum leakage detector was used; this equipment was jointly developed by the Rocket General Assembly Plant and the Lanzhou Physics Institute. This equipment uses a pressure filling and leakage detection technique. In a leak inspection, more than 100 differently shaped outer covers were used; these small outer covers only have a volume of 0.5 ml, and large covers can contain the entire bottom of a fuel tank. The fuel tank is then filled with gas and a vacuum is induced inside the cover; a probe is used to detect the leakage rate.

As proven in practice, no leakage incidents occurred for rockets and satellites checked with these items of equipment, whether in ground tests or space flights.

(H) Computers

In 1969, once the model 109C transistor general digital computers were made available, these computers were used in

aerospace technology. These computers were developed by the Computation Technology Institute of the Chinese Academy of Sciences; all components and parts of this computer were made in China. The operational efficiency, stability, and reliability of the computer were first-rate in China. In the next 16 years, these computers provided numerous important data and decision-making bases for theoretical computation of various models of carrier rockets developed in China. The model 109C computers served in making theoretical computations of flight orbits of Changzheng No. 1 carrier rocket and Dongfanghong No. 1 satellite in April 1970, the trajectory data computation of long-range rocket that flew over the Pacific Ocean in May 1980, and some data computation of trajectories for Changzheng No. 3 rocket in April 1984. People called this computer the merit computer. These computers are old in the eighties; however, these computers accomplished outstanding merits in aerospace activities. In the early eighties, various versions of newer computers were generally applied in the aerospace industry system; China is building a computer network centering on the advanced large computer.

(I) Measurement technology

In aerospace engineering, the measurement technology is related to the entire process of development; this is the technical basis for ensuring product performance indicators. The measurements are precursors for scientific development. The measurement task is to maintain standardization and precision of measurements, and to standardize the state's measurement systems, so that the measurement values can be transferred to the first lines of scientific research, production, and experimentation in order to ensure consistency of instruments, meters, and equipment in their measurement values. Thus, product quality and coordination of rocket and satellite systems can be ensured. Various aerospace products have their respective requirements on

parameters, measurement range, frequency band, and precision; however, these parameters, measurement range, frequency bands, and precision should have strict and standard measurement management for a unified and highly precise measurement standard. The measurement and testing of some aerospace products require on-site real-time, dynamic and automated system-wide comprehensive measurements and tests.

The establishment of unified and highly precise standards are the struggling target of measurement scientific personnel. Aerospace technology is difficult apart from precise measurement standards.

When the aerospace undertaking was beginning, China's aerospace measurement technology was in the explorative stage. With the development of copying P2 guided missiles, many difficult measurement problems and related problems of precise measurements and tests confronted aerospace measurement personnel. These difficult problems were solved one after the other by the mass scientific and technical personnel as well as workers via their intelligence and talents. With the advances in aerospace activities, the measurement stations of radio, microwave, time frequency, length, heat, force, electrovacuum, and electrical engineering were founded, thus forming a rank-and-file contingent for transferring measurements and management standards. Developed by the various stations or by the related departments via coordination, there are balances of a 3 ton measurement range, force measurement device of a 500 ton measurement range, gas distribution balance of 200 kg, laser gyroscope spherical bowl measurement and test instrument, sensitivity measurement and test apparatus, pulsation pressure calibration apparatus, frequency short-circuiting and stable frequency detectors, as well as calibration apparatus of low vacuum, high vacuum, and ultra-high vacuum. Thus, a number of optical instruments were innovated in solving problems of

precision measurement and testing. Moreover, 56 first-class measurement standard parameters were prescribed: vibration standards of high, intermediate, and low frequencies, thermal noise, low-temperature noise, radio frequency attenuation standards, and 10,000 liter bell-shaped cover.

These above-mentioned large experimental items of equipment and facilities are just a cross-section of aerospace experimental technology; however, they can illustrate that these instruments have exploited important rules in aerospace activities; these items of equipment will become a resourceful material basis for continued development of aerospace activities.

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